Vol. XLVI. DECEMBER, 1901.

AMERICAN SOCIETY OF CIVIL ENGINEERS

INSTITUTED 1852.

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No. 906.

THE LAWRENCE, MASS., CITY FILTER: A HISTORY OF ITS INSTALLATION AND MAINTENANCE.

By Morris Knowles, Assoc. M. Am. Soc. C. E.,
and
Charles Gilman Hyde, C. E.

Presented June 5th, 1901.

WITH DISCUSSION.

Introductory.—The preparation of this paper has been undertaken in order that the story of this interesting engineering work, and, particularly, an account of its operations, might be recorded in one narrative, with all the necessary data at hand for a study of conditions and effects produced thereby.

One of the writers was a member of the Lawrence Water Board* for five years, from January 1st, 1895, and, during that time, had opportunity to learn the details of the cost of operation and the results of changes in methods. The other has had occasion to study the records and determine the efficiency of the filter from the standpoint of the unbiased investigator.

* The members of the Water Board for 1901 are Mr. A. S. Robinson, President, and Messrs. Daniel Gallagher, J. J. Desmond, Edward Arundel and Charles Donovan, to whom the writers are indebted for allowing much of the information in the files of the Board to become available.

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Many of the data and statements in portions of the paper preceding and including "Description and Construction" have been largely compiled from more complete descriptions in other publications. This action appears amply justifiable on account of the value of having these data, for which no originality can be claimed, in comprehensive form for reference and study. The writers make this statement in order that there may be no misunderstanding as to the authority for all such information, the credit for which has been given in each case.

LAWRENCE.

The City of Lawrence is situated in the northeasterly part of the State of Massachusetts, not far from the New Hampshire boundary line. It is the second largest city in Essex County, and ranks as the seventh in population among those of the State. The entire area, which is about 7.3 sq. miles, is rather compactly built up, the larger and denser settlement being on the northerly bank of the Merrimac River, with a smaller and now rapidly developing section south of the stream. The growth of the city since its first settlement in 1843 has been vigorous, and the statistics of the population, as given by the successive census reports, are given in Table No. 1.

TABLE No. 1.—POPULATION OF LAWRENCE, MASS.

Date.	Enumeration by	Population.
1847	Town.	3 577
1848	Town.	5 949
1849	Town.	7 225
1850	U. S.	8 282
1855	Mass.	16 114
1860	U. S.	17 639
1865	Mass.	21 698
1870	U. S.	28 921
1875	Mass.	34 916
1880	U. S.	39 151
1885	Mass.	38 862
1890	U. S.	44 654
1895	Mass.	52 164
1900	U. S.	62 559

The city is distinctively a manufacturing community, and its population, like others of New England having similar industries, embraces, besides native Americans, many of foreign descent. A large proportion of the people has lived in well-constructed tenement buildings, owned by the mill corporations, and maintained, particularly during the early history of the town, under favorable sanitary regulations; all of which

tended to promote a state of general good health, superior to that of many manufacturing cities of this character. At the present time, while there is a restricted portion in which the conditions are more like those which usually obtain in thickly populated factory cities, the foregoing statement in regard to the hygienic conditions is true for most of the city.

Merrimac River.

Water-Shed.—The Merrimac River is formed by the union of the Pemigewasset and Winnipiseogee Rivers, near the central part of New Hampshire. Thence, it takes a generally southerly course to a point in the neighborhood of Lowell near the Massachusetts–New Hampshire boundary line, where it turns sharply and flows in a northeasterly direction to the Atlantic Ocean. The source of the first-named tributary is in the southwesterly slopes of the Franconia Mountains, while the latter flows from a large lake of the same name, and the water-sheds of both rivers are very rugged. As the main river flows southward, the country becomes less mountainous, until in the southerly portion of New Hampshire and the northerly part of Massachusetts, it is rolling and abounds in hills which are often steep but of no great height. Along the lower course of the river the water-shed area is quite flat, particularly in the down-stream portion of the valley of the Concord River (the principal tributary entering the Merrimac within Massachusetts), where large areas of flat meadow and swamp land border upon this stream.

Sanitary Conditions.—At Concord and Manchester in New Hampshire and at Lowell and Lawrence in Massachusetts, large water powers have been developed. These are quite thoroughly utilized by many textile and other industries, in some of which steam is also used as an auxiliary source of power. The tributaries of the river above Lawrence have also been developed for water power at many points, at which mills (the largest of which are at Nashua, N. H.), have been erected and are in operation. From all these places manufacturing refuse and waste of various kinds is turned directly into the stream. Above Lawrence the river receives the unpurified sewage of Concord, Franklin, Laconia, Manchester and Nashua in New Hampshire, and of Fitchburg, Hudson, Leominster and Lowell in Massachusetts, having, in 1900, an aggregate population of 258 751. It further receives the purified effluents from sewage disposal systems in the towns of Clinton,

Concord, Framingham, Marlborough, Natick and Westborough in Massachusetts, having, according to the census of 1900, a total population of 59 118.

In 1878 the Legislature of Massachusetts, by special enactment, made the Merrimac River a free receptacle for sewage, the quantity of which has been greatly increased from year to year, until, in 1900, the amount of such pollution entering the stream directly is estimated to have been 1 gall. in every 40* flowing in driest times in the stream past the city of Lawrence, or 1 gall. in every 200,* representing the average flow of the stream. Referring to the pollution of the Merrimac River, prior to its purification for the water supply of Lawrence, Mr. Hiram F. Mills, as Chairman of the Committee on Water Supply and Sewerage of the Massachusetts State Board of Health, in a communication to the Mayor of the city, dated January 30th, 1891, stated:

"The amount of sewage that has directly entered the river and its branches during the chemical examinations of the past three years (1887–1890), has been estimated to be about 1 gall. in 600 galls. of the river water passing Lawrence."† A comparison of these data indicates that the increase of polluting matters entering the river during the past decade has been very marked.

The total area of the Merrimac River water-shed above the Lawrence Dam is estimated to be 4 630 sq. miles, containing a total population of 480 000,‡ or about 104 persons per square mile, of which figure about 65 persons represent urban population in cities and towns having in 1900 over 5 000 people.

The water power of the stream at Lawrence has been developed and is controlled by the Essex Company, which, from 1845 to 1848, constructed a long dam, averaging 32 ft. in height, across the stream near the center of the city. The mill pond formed by the dam extends up stream to

* These figures, respectively, are based upon the assumption that the Merrimac River receives an amount of crude sewage equivalent to 75 and to 100 galls. per day per person resident on the water-shed above Lawrence in cities provided with sewers which discharge without purification directly into the stream.

† Annual Report, Massachusetts State Board of Health, 1890, p. 533.

‡ This figure has been obtained by using as a basis the estimated population, in 1885, living on the water-shed of the Merrimac River above the dam at Lawrence (Special Report, Massachusetts State Board of Health, 1890, Part I, p. 442). From these data, the population of rural districts on the water-shed in both New Hampshire and Massachusetts was obtained, and the numbers adjusted to the year 1900. The adjustment was accomplished by using the estimated percentage of growth in the entire rural districts of both States during the period from 1885 to 1900. The population of the cities and larger towns upon the water-shed of the river above Lawrence was determined accurately from the census enumeration of 1900. Approximately the same result was obtained by apportioning the 1900 census figures of population of the various cities and towns on the water-shed according to the position of the divide line. The total water-shed population thus obtained is believed to represent quite closely the actual conditions at the present time.

Hunt's Falls, in Lowell, a distance of about 9 miles, and the entire volume of water stored therein is roughly estimated to be equivalent to about 2 hours' flow of the river during times of flood; while, during the driest periods, from 2 to 2½ days may be required to entirely change the water stored in the pond above the dam. The ordinary dry-weather flow of the river, which is comparatively large owing to the very considerable storage obtained in Lake Winnipiseogee and other controlled bodies of water in the lake region of New Hampshire, is estimated to be one-fourth of the average yearly flow, and is probably sufficient to change the water in the pond above the Lawrence Dam in from 30 to 36 hours.

Muddiness of River.—Usually, the water of the Merrimac at the intake of the Lawrence Water-Works does not contain a large amount of suspended matter, such as clay or silt, the normal quantity being estimated to be about 10 parts per million.* During freshets, however, the amount of silt carried by the stream is greatly increased; but this material, being of comparatively coarse structure, requires no great length of time for settlement, so that in a few days after severe storms, the water again assumes its normal character.

In April, 1895, during a period of severe freshet, a study was conducted at the Lawrence Experiment Station to determine the maximum quantity of solids contained in the water of the river at such times, together with the rapidity of settlement and the consequent interval required by the water to return to its normal condition.† On April 16th, during the height of the flood, the water flowing in the river was found to contain total solids to the amount of 1 110 parts per million, of which, 57 parts, or about 5.1%, represented organic matter lost on ignition. A tube 2½ ins. in diameter and 6 ft. long was filled with this water and was allowed to stand quiescent for 24 hours, at the end of which time samples were taken from various depths for analysis, the results of which showed that uniformly in the upper 5 ft. of the tube the water contained from 82 to 83 parts per million of total solids, while in the lower foot the heavier particles, representing nearly 1 030 parts per million, had collected. The percentage of loss on ignition of the solids found in the upper portions of the tube varied from 23 in the first to 30 in the fifth foot from the top.

* Report on the Purification of the Washington (D. C.), Water Supply, 1901; page xiii.

† Annual Report, Massachusetts State Board of Health, 1895, pp. 527-528.

The results of examination of the water flowing in the river on April 16th and on eight succeeding days are given in Table No. 2.

TABLE No. 2.—TOTAL SOLIDS IN MERRIMAC RIVER WATER DURING THE FRESHET OF 1895.

Date.	Total Solids.	Loss on Ignition.	Percentage of loss on ignition.	Percentage of the solids in river water on April 16th.
	Parts per million.			
April 16.....	1 110	57	5	100
" 17.....	452	82	18	41
" 18.....	162	38	24	15
" 19.....	111	27	24	10
" 20.....	78	14	18	7
" 22.....	74	24	32	7
" 23.....	69	16	23	6
" 24.....	53	13	24	5
" 25.....	45	8	18	4

NOTE.—The average Residue on Evaporation, determined on samples of Merrimac River water after passing through filter paper, has been equal to about 40 parts per million. The Total Solids in excess of this quantity probably, therefore, represents, quite closely, Suspended Matter carried by the stream.

By April 25th the river had returned to its usual condition, the total period during which the amount of silt, due to the freshet, was abnormally high being 9 days; while only 3 days were required either for 90% of the solids to settle out of the water, or else for the very turbid water to pass by and water containing only 10% of the maximum amount of mud to take its place.

Table No. 3 has been prepared in order that certain data relative to the water-shed and the character of the water of the Merrimac may be compared with those of other streams in regard to which similar information is available.

CONSIDERATION OF AN IMPROVEMENT OF THE WATER SUPPLY.

Old Filter Gallery.—When the water-works were constructed, from 1873 to 1876, provision was made to take water directly from the Merrimac River through a 36-in. cast-iron pipe, 132 ft. long, beginning at the river, and in extension, through 38 ft. of 4-ft. brick conduit, to a well located under the pumping station. It was also provided that clarified water should be drawn from a stone and brick filter gallery, 8 ft. in width and height, and 300 ft. long, extending down stream from the pumping station at right angles to the direct inlet pipe and conduit. The elevation of the bottom of the conduit, and that of the gallery, is

NOTES TO ACCOMPANY TABLE NO. 3.

Merrimac River.—Results were obtained by averaging the records in the reports of the Massachusetts State Board of Health.

Maximum total solids determined on sample collected during height of flood, in April, 1895.

Maximum suspended matter estimated from a comparison of the above figure with the maximum amount of total solids determined on samples after passing through filter paper.

Average suspended matter represents estimate by Board of Experts, in "Report on Purification of Washington (D. C.), Water Supply," 1901, p. xiii.

"Oxygen consumed" is the average for 7 years (1893–1899).

"Total hardness" is the average for 10 years (1890–1899).

"Bacteria" is the average for 7 years (1893–1899).

For remarks on method of analyses, see note, Table No. 17, page 299.

Hudson River.—The urban population in places of 1 000 inhabitants and over is 59; the total was obtained by estimating an increase of 15% in the rural population for the ten years from 1890-1899. See *Transactions*, Am. Soc. C. E., Vol. xliii, p. 248.

Results of examination of the water in the back channel of the river at the intake to the filter plant were kindly furnished by George I. Bailey, M. Am. Soc. C. E., Superintendent of the Albany Water-Works.

Bacterial result represents data from September, 1899, to September, 1900, inclusive.

Potomac River.—Determinations made on river water which had settled about 3.5 days.

See "Report on Feasibility and Propriety of Filtering the Water Supply of Washington, D. C., 1900," pp. 12, 13, 79 and 89.

Bacteria per cubic centimeter represent average of examinations during 8 months (July, 1899, to February, 1900). *Ibid*, pp. 42 and 87.

Estimated average suspended matter in unsettled Potomac River water = 80 parts per million. See "Report on Purification of Washington (D. C.), Water Supply, 1901," p. xiii.

Allegheny and Monongahela Rivers.—Population per square mile represents the estimated urban population only of the principal cities and towns, some of which, however, had not more than 500 inhabitants.

Data compiled from "Report of Filtration Commission," Pittsburg, 1899, pp. 30 to 32, 238 and 271.

Bacterial result for Allegheny River is the average from August, 1897, to January, 1900, inclusive. See *Journal*, New England Water-Works Association, September, 1900, Vol. xv, No. 2, pp. 154 to 156.

Ohio River at Cincinnati.—See "Report on Water Purification," Cincinnati, 1899, pp. 13 and 19. Total water-shed area, including Licking River = 75 700 sq. miles. Figure for population on water-shed includes urban districts only. Averages for "Color" and "Oxygen Consumed" calculated from data on pages 32-36, *Ibid*.

Ohio River at Louisville.—See "Report on Feasibility and Propriety of Filtering the Water Supply of Washington, D. C., 1900," p. 89; from table prepared by George W. Fuller, Assoc. M. Am. Soc. C. E. See also "Report on Water Purification at Louisville, 1898," pp. 15, and 21 to 31.

Figure for population on water-shed includes total inhabitants. The urban population in 220 cities and towns is estimated to be 20 per square mile.

Averages for "Color and Oxygen Consumed" were calculated from data on pp. 21-31, *Ibid*, excluding the months of August and December. Bacterial result is for the period from October, 1895, to July, 1897, inclusive, excluding August to January, 1897, *Ibid*, p. 39.

* This figure, as estimated by Allen Hazen, M. Am. Soc. C. E., on a new basis, is 80. See page 312.

† Total hardness of Potomac River water, as obtained from statement by Mr. R. S. Weston. See page 320.

TABLE No. 3.—Data of Water-Sheds and Average Composition of Water of Certain Representative Rivers in Eastern United States.

Name of river.	Point of measurement and examination.	Water-shed area, in square miles.	Estimated population per square mile of water-shed, 1900.	Chemical Determinations.												Average bacteria per cubic centimeter.	Period covered by analyses.
				Average color.	Parts per million.												
					Total solids.		Suspended matter.		Average nitrogen as				Average oxygen consumed.	Average chlorine.	Average total hardness.		
					Maximum.	Average.	Maximum.	Average.	Ammonia.		Nitrites.	Nitrates.					
									Free.	Alb.							
Merrimac.....	Lawrence	4 630	104	0.39	1 110	39	1 050	10	0.052	0.195	0.002	0.079	5.2	2.1	12.4	8 400	1888 to 1899.
Hudson.....	Albany	8 240	93*	0.37	163	128	72	13	0.112	0.305	8.008	0.054	6.1	9.39†	72.0	27 300	March to September, 1900.
Potomac.....	Washington...	11 040	45	0.20	190	130	100	15	0.010	0.100	0.001	0.700	3.0	3.0	93.0†	3 800	1897 to 1900.
Allegheny.....	Pittsburg	11 400	24	0.27	806	156	726	42	0.019	0.117	0.000	0.705	.....	21.7	35.5	17 900	August, 1897, to July, 1898.
Monongahela..	Pittsburg	7 600	24	0.20	872	208	756	64	0.066	0.149	0.000	0.880	.....	11.8	43.6	19 200	August, 1897, to July, 1898.
Ohio.....	Cincinnati.....	72 400	24	0.11	2 556	350	2 333	230	0.025	0.290	0.003	0 600	5.7	10.0	.....	20 000	1898.
Ohio.....	Louisville	85 000	66	0.18	5 638	500	5 311	350	0.044	0.370	0.008	0.770	7.1	17.0	.....	14 000	1895 to 1897.

about Elevation 26, the same as the floor of the pump-well, or practically 11 ft. below the usual low water in the river. The filter gallery was constructed in a stratum of coarse gravel, with side-walls laid in cement but not thoroughly tight. The bottom consists of cross-blocks of granite, 1 ft. wide and spaced 10 ft. apart, filled in between with small stone. The roof is a brick masonry arch, 8 ins. thick.

It was the original intention to use water from the filter gallery at such times as the river carried undesirable amounts of silt in suspension, although at the time of construction it was uncertain whether or not the full supply for the city could be obtained for all time through this structure. Its inadequacy to meet the requirements of the city was soon apparent, and, in the first annual report of the Water Board, dated January 1st, 1877, it was stated that sufficient water would not percolate through the gravel to the gallery, and that it had become necessary to excavate a channel between this structure and the river. The channel had, at the lower end, a direct open connection with the river, which allowed the water to flow back along the side of the gallery. By this means its capacity was, for a time, apparently increased, though not to the required amount, and a further extension of the works down stream was considered. An enlargement of the channel, in 1878, failed to produce an adequate increase in the yield from the gallery. The report of the Water Board for this year gave evidence of the development of a belief that the importance of a sufficient supply of clear, wholesome water demanded some better mode of filtration than that then in use.

In the eighth annual report, for the year 1883, it was stated that it was apparent that the gallery was gradually silting up, and that most of the water came from the land side. It is evident, therefore, that from the very first, the filter gallery was incapable of furnishing the whole supply for the city, and that its capacity constantly diminished until it was practically insignificant, inasmuch as the flow from the hillside was inconsiderable compared with the demands of the city's consumption.

Various Projects.—Upon several occasions, after the introduction of a public water supply, it was noticed that outbreaks of typhoid fever in Lawrence followed a prevalence of the same disease in Lowell, and in the latter part of 1890 attention was again called with anxiety to the excess of this disease in the city. The citizens, generally, boiled the water for drinking purposes, and many of the schools, mills and dwelling-houses were supplied from springs in the suburbs. On January 31st,

1891, a conference was held between the Water-Works Committee of the City Councils and the past and present members of the Water Board. This meeting resulted in a better understanding of the need of an unpolluted drinking water for the people, but there was a diversity of opinion as to the relative merits of an entirely new and uncontaminated supply from some of the New Hampshire ponds, and the old supply from the Merrimac River, suitably purified by filtration.

About the middle of March, 1891, "The Salem Water Company" was incorporated by the New Hampshire Legislature, with the ostensible purpose of furnishing water to the town of Salem, N. H.; but at the same time there were granted to the company such broad charter powers that other rights to the waters of southern New Hampshire were precluded. Meanwhile, a long series of experiments conducted by the State Board of Health, under the supervision of Mr. Hiram F. Mills, since the establishment of the Experiment Station at Lawrence in 1887, had given evidence that the water of the Merrimac River could be rendered entirely satisfactory and safe for drinking purposes by intermittent sand filtration. The Water Board on June 22d, 1891, presented to the City Councils a report covering the whole question of the improvement of the supply, in which were stated the several objections to a supply from wells, and to a supply from Great Pond in North Andover, or from ponds in southern New Hampshire, and finally recommended that the use of water from the Merrimac River be continued, but that it be filtered—the system of filtration to be determined subsequently. This report was accepted and referred to the Committee on Water-Works, but no other action was taken. About this time a petition was presented to the city government by prominent citizens, and discussed at a joint convention held July 22d, 1891, asking for the appointment of a commission, independent of the Water Board, to consider the entire water supply problem, but no action upon the petition was taken.

*Advice of State Board of Health.**—The Water Board of 1892, on February 29th, requested the advice of the State Board of Health relative to mechanical filtration. The latter board, on March 9th, stated that it was unable to advise that any of the rapid mechanical filters then in use would purify the Merrimac River water sufficiently to insure exemption from typhoid fever, but they did advise, however, that by a process of slow intermittent filtration at a rate of 400 000 galls. per acre per day, bac-

* The information in this section has been obtained from the Reports of the Massachusetts State Board of Health.

teria could be very completely removed. On June 5th, 1892, the State Board of Health, in answer to a subsequent communication, dated May 6th, relative to filtration through sand, advised the Water Board that a satisfactory purification of river water would be obtained with sand filters of proper material 5 ft. deep, operated at a rate of 1 500 000 galls. per acre daily. It was also stated that, in order to produce satisfactory results, it was deemed necessary to free the river water from the sediment carried during freshets, before applying it to the filters, which could be located conveniently upon the hill just above the reservoir. To accomplish the preliminary clarification of the water, it was advised that a filter of coarse sand should be provided at the river bank. The Board of Health also advised that, in its judgment, a marked decrease in the death rate from typhoid fever could be brought about simply by the construction and proper maintenance of the filter referred to, at the river bank. Furthermore, it was strongly recommended that the excessive death rate from typhoid fever demanded that some method of purifying the water be adopted at once.

Filter Construction.—The Water Board concluded that the project to build a filter at the river bank was the more feasible, and decided to proceed with its construction, according to plans and directions to be given by the State Board of Health. On August 4th, 1892, a visit of the State Board of Health, the Water Board and city officials was made to the proposed site. The City Councils granted the Water Board permission directly afterward to expend $20 000 of its earnings for the purpose of filter construction. Ground was broken on September 10th, and 150 men placed upon the work. On November 13th, an additional $10 000 was allowed for its further prosecution, and this sum was found sufficient until the end of the year.

At the beginning of the new year, owing to a feeling of uncertainty on the part of the City Councils as to the promised action of the filter in purifying the river water, there was considerable discussion in regard to renewing the work of construction. However, it was finally decided on February 13th, 1893, to proceed with diligence, under the joint direction of the Water-Works Committee of the City Councils and the Water Board, the cost being provided from the Incidental Fund. After October 1st, the expenditures were again charged to the water-works account. The filter was completed and water turned on Sep-

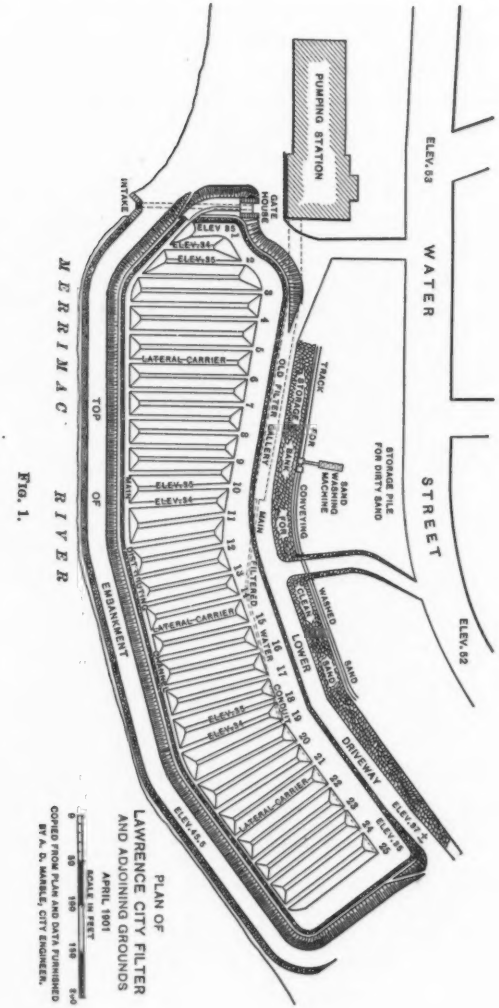

PUMPING STATION
ELEV. 53
WATER
STREET
ELEV. 52
GATE HOUSE
INTAKE
ELEV 95
ELEV. 94
ELEV. 93
TRACK
FOR
SAND
MACHINE
CONVEYING
BELT
FOR
STORAGE PILE FOR DIRTY SAND
OLD FILTER GALLERY
MAIN
FILTERED
WATER
CONDUIT
WASHED
SAND
CLEAN
SAND
LOWER
DRIVEWAY
ELEV. 87.5
ELEV. 86
ELEV. 84.5
LATERAL CARRIER
LATERAL CARRIER
LATERAL CARRIER
ELEV. 95
ELEV. 94
ELEV. 93
ELEV. 93
ELEV. 94
ELEV. 95
TOP
OF
EMBANKMENT
MERRIMAC
RIVER
PLAN OF
LAWRENCE CITY FILTER
AND ADJOINING GROUNDS
APRIL 1901
SCALE IN FEET
0 50 100 150 200
COPIED FROM PLAN AND DATA FURNISHED
BY A. D. MARBLE, CITY ENGINEER.

FIG. 1.

tember 20th, 1893, and it has continued to furnish the city with filtered water to the present time.

The cost of construction of the filter to the end of the year 1893 was about $65 500. Additional construction, for the most part undertaken with a view to facilitate operations and render the maintenance more efficient and less expensive, has been carried out from time to time, the cost of which appears in detail in a later portion of this paper.

Description of the Filter.*

The Lawrence City Filter was designed by Mr. Hiram F. Mills, Chairman of the Committee on Water Supply and Sewerage of the State Board of Health of Massachusetts, to whom credit is due for giving his time and energy to bring about such a benefit to the city.

Location and Dimensions.—The filter is located, as shown in Fig. 1, on the northerly bank of the Merrimac River, about one mile above the Essex Company's Dam, and immediately east of the pumping station.

It is somewhat irregular in outline, having a total length of about 750 ft., an average width of 140 ft., and a surface area, including the main carrier, of 2.44 acres. The filter surface is divided by transverse carriers into 25 portions or beds, each having an average width of 30 ft. This gives an available filtering surface, including lateral carriers, of 2.36 acres; or, without these carriers, of about 2.3 acres.

In constructing the filter, the bed and bank of the river were excavated generally to 7 ft. below usual low water (equal to Elevation 37, which is the top of the flash boards on the Essex Company's dam), for a distance of about 150 ft. southerly from the old filter gallery, and in the river bank east, or down stream, a sufficient distance for the total length of the filter. Suitable material from the excavation was placed in a tight embankment on the ends and on the side toward the river, of such a height as to be 9 ft. above usual low water, and high enough to exclude freshets.

Main Conduit and Underdrains.—The underdrain pipes which extend across the filter from north to south, were arranged with centers about 30 ft. apart. For a width of 5 ft. along the line of drain pipe the exca-

* This description is largely abstracted from the paper by the designer, entitled "The Filter of the Water Supply of the City of Lawrence, and Its Results;" to which the writers refer for further details not given here. (See 25th Annual Report of Massachusetts State Board of Health for 1893, pp. 545-560.)

vation was continued to Elevation 29, and midway between the lines of underdrains, for a width of 5 ft., the depth of the excavation was only to Elevation 31. The bottom between these two levels, for a width of 20 ft., was excavated with a slope of 1 in 10. Thus it will be seen that the bottom of the filter when excavated, ready to receive the filtering material, was waved, with alternate level ridges between the lines of underdrains, and flat valleys in which the underdrains themselves were placed.

The old filter gallery extended easterly along the northerly edge of the excavation for the filter, from the pumping station at the westerly or up-stream end, through a distance of 300 ft. to a point about opposite Bed No. 11. From the gallery a main conduit was extended eastward in the filter beds, running parallel with and about 20 ft. south of the northerly edge of the filter. This conduit is circular in shape and its westerly portion is 4 ins. thick, and built of brick laid without mortar in the end joints, thus allowing spaces a little more than $\frac{1}{8}$ in. wide for the entrance of filtered water. The conduit is 2 ft. in diameter for 105 ft. from the end of the filter gallery; thence 20 ins. for 120 ft.; 16 ins. for 65 ft.; 12 ins. for 30 ft.; continuing with successive lengths of 30 ft. each of vitrified pipes having diameters of 10, 8 and 6 ins., respectively. The entire conduit was surrounded with 8 ins. of gravel, the inner 4 ins. being of stones about 2 ins. in diameter, and this was covered with layers of stones of decreasing sizes.

From the conduit and old filter gallery, which was pierced at suitable places for the purpose, lateral underdrains of vitrified pipe were laid in a southerly direction upon the excavated bottom, with a slope of 1 in 100, for a distance equal to four-tenths of that from the main conduit to the southerly edge of the filter. Beginning at the main conduit, the pipes were laid in the following order: One length of 10-in., two lengths of 8-in., from 35 to 65 ft. of 6-in., ending with three lengths of 4-in. The pipes were placed so that the spigot end of one approached, but did not enter, the bell end of the next, and the drains throughout were covered by a 4-in. layer of 2-in. gravel. Upon this layer, which averaged about 6 ins. in actual depth, there were placed successive courses of gravel of the following sizes and of the approximate thicknesses (given for an average section) to make a total of 12 ins. of underdrain material: 2 ins. of $1\frac{1}{2}$-in., 1 in. of $\frac{3}{4}$-in., 1 in. of $\frac{3}{8}$-in., 1 in. of $\frac{3}{16}$-in. gravel, then 1 in. of coarse mortar sand. The course of

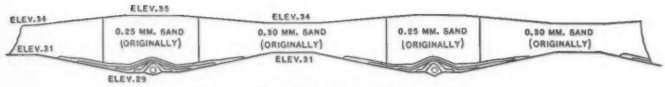
$\frac{3}{16}$-in. material was spread out to a width of 17 ft., and the last course was spread out to a width of 20 ft. Beyond the pipes, the largest stones, forming the lowest course, were laid upon the surface of the excavation and were spread out to a general width of 5 ft., with the next courses each spread out a little beyond the one just below. The $1\frac{1}{2}$-in. gravel extended southerly to within 12.5 ft. of the edge of the main distributing channel, with the end of the coarse sand 7.5 ft. further south.

The largest stones used in the underdrains were selected by hand, and, if covered with dust or dirt, were washed. The smaller sizes were obtained by screening, but were not washed. The stones of the two larger sizes, namely, 2-in. and $1\frac{1}{2}$-in., were placed by hand at the open joints of the pipes, but the layers of smaller sizes were all shoveled into place. The arrangement of all the above-mentioned material, including the sand, is shown for several sections in Fig. 2.

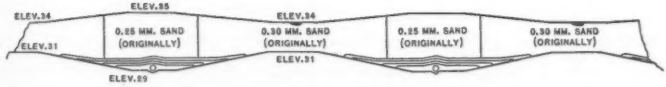
Filter Sands.—Immediately over the center lines of the underdrains, that is, over that portion of the beds excavated to the greatest depth, and extending 5 ft. on either side, there was placed a body of sand, with a maximum depth of 5 ft. in the center. Over the ridges of the excavation for the filter, midway between the lines of underdrains and for a distance of 10 ft. on either side, there was placed a body of sand, having a minimum depth, over the flat portion of the ridge, of 3 ft. The effective size of the sand over the underdrains was approximately 0.25 mm. and of the remainder was about 0.30 mm.

It will be seen by this construction that the lowest portions of the filter surface are those directly over the ridges of the excavation and half way between the underdrains; the general elevation of the surface of these parts being 3 ft. below the usual low-water elevation of the river, and 1 ft. below the sand surface over the underdrains. For a width of 5 ft. over the center lines of both ridges and underdrains the surface of the sand is flat, and between these level areas the sand has a slope of 1 in 10. This form of surface is such that water can be readily introduced upon the filter to refill, without producing currents sufficiently rapid to cause appreciable disturbance.

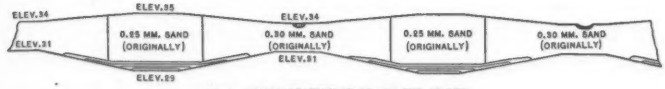
Sand and gravel for the filter were obtained from a large deposit back from the river, and distant about $\frac{7}{8}$ mile from the works. The material found at this place was by no means uniform, and suitable grades were obtained by selecting certain layers and pockets, and by judicious screening and mixing of these various kinds.



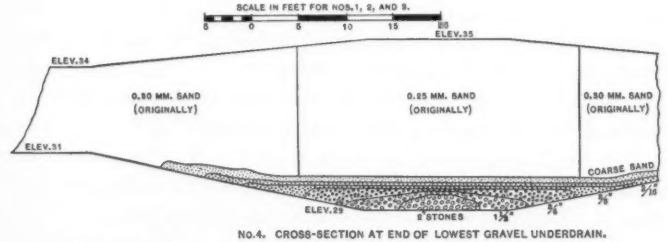
No.1. CROSS-SECTION AT NORTH END OF BED.



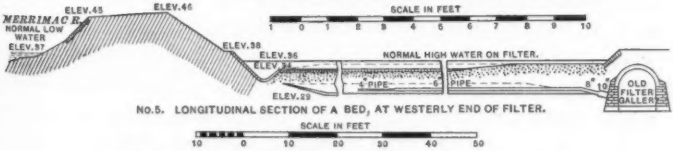
No.2. CROSS-SECTION AT BEGINNING OF PIPE UNDERDRAIN.



No.3. CROSS-SECTION AT SOUTH END OF BED.



No.4. CROSS-SECTION AT END OF LOWEST GRAVEL UNDERDRAIN.



No.5. LONGITUDINAL SECTION OF A BED, AT WESTERLY END OF FILTER.

TYPICAL SECTIONS OF UNIT BEDS IN LAWRENCE CITY FILTER.

APRIL, 1901.

COPIED FROM PLAN FURNISHED BY A. D. MARBLE, CITY ENGINEER.

FIG. 2.

Care was taken in depositing the sand in the filter to render the mass as homogeneous as possible. It was placed in two layers. The first layer was covered with planks as fast as deposited, and, upon the plank platform, loads were hauled and dumped near the edge, so that a part fell naturally into place, and the remainder was shoveled. Material, exposed to sun and wind before being finally placed, was shoveled over, to lessen the danger from the collection of the larger particles at the bottom of dry piles of sand. The second layer was dumped upon platforms resting on the first and then shoveled to position, the compacted sand in the first layer beneath the planking being first spaded to a depth of 1½ ft. before the second layer was placed.

Intake and System of Distribution.—The direct conduit, by which water was formerly supplied from the river to the pumping station, is at the westerly or up-stream end of the filter, and the flow through it was controlled by a gate at the inner end. About 40 ft. southerly from the engine-house, the top of this conduit was pierced and two cast-iron pipes were set in a chimney built at this opening. The pipes are 2 ft in diameter, and each has a gate, the center of which is 2 ft. below the usual low water in the river. The use of one of these pipes to supply a possible future extension of the works west of, or up-stream from, the present filter has been suggested.

The other pipe discharges into the main carrier, or distributing channel, which extends along the entire southerly edge of the filter to a point within about 35 ft. of the easterly end. The edge of this channel toward the filter remains level throughout its length, the elevation of this edge corresponding with the uniform elevation of the sand surface of the southerly edge of the filter, or 3 ft. below usual low water in the river. At the upper or westerly end, this carrier has a semicircular section of 3 ft. radius, but as it extends easterly, the width and depth constantly decrease, so that at the lower end its width is reduced to 2 ft., and the bottom is only 6 ins. below the level of the inner edge.

In each of the level valleys of the sand surface a shallow distribution carrier extends from the main channel to a point 32 ft. from the opposite or northerly side of the filter. At the main channel, each lateral carrier is 2 ft. wide and 3 ins. deep, decreasing to a width of 1 ft. and a depth of 1 in. at the northerly end. The edges of these distributors are level and at the same elevation as the inner edge of the main carrier.

The main carrier is constructed of cobble paving stones, from 4 to 6 ins. in diameter, laid in Portland cement mortar on a gravel bed 8 ins. thick. The lateral carriers are made of cobble stones, 4 ins. in diameter, laid in Portland cement mortar directly on the sand surface. The interior surface of all these channels was made smooth by a coat of mortar.

Description and Results of Operations.

Methods in General.—From the time when the filter was first started it has been customary to fill from above over the surface. The water from the river is turned on gradually at the gate-house at the westerly end of the filter, allowed to pass out into the main channel, and from this along the lateral carriers to the different portions of the filter. At first the water settles into the sand nearest the carriers, but at length rises slowly and covers the entire sand surface. When a depth of from 1½ to 2 ft. of water has been obtained over the carriers the pump at the station is started. The more slowly the whole process is conducted the smaller will be the amount of entrained air in the filter, and the initial loss of head correspondingly less. At various times of urgency undue haste in refilling has actually caused loss of time, inasmuch as the amount of air retained in the bed has resulted in creating excessive losses of head shortly after starting, causing a reduced rate of filtration below that which might have been obtained with more deliberate action.

Almost without exception the water in the river has been high enough to flow upon the filter by gravity and maintain the water surface at a suitable elevation; but upon one occasion, in January, 1900, for a period of about 10 days, the water in the river was approximately at Elevation 36, and it was necessary to resort to pumping to supply water to the filter. Two centrifugal pumps of 8-in. and 6-in. discharge were used. The former was purchased and housed permanently for regular use in draining the filter, as well as to serve as a safeguard in case of unusually low water in the future.

In operating the filter it has been customary to maintain the water surface upon the beds at Elevation 36, or 1 ft. below the usual elevation of low water in the Merrimac River. This is equivalent to a depth of 2 ft. over the lateral distributing carriers, and of 1 ft. over the crowns of the beds when at grade. During the coldest weather, when it has not

been possible to scrape the surface, the water has frequently been raised to Elevation 37, and at less frequent intervals to Elevation 37.50 in order to force the required amount through the filter.

Whenever the filter is so clogged that the maximum loss of head will not force a sufficient quantity through it, the filter is shut down and drained in the following manner: The inlet gate is closed, preventing the further entrance of river water upon the filter, and pumping is continued at a constantly decreasing rate until the water already on the beds passes into the sand and below the surface to such a depth that laborers can work upon it. Since January, 1900, this operation has been greatly facilitated by the use of the 8-in. centrifugal pump provided with a double suction and discharge, so arranged as to force water from the filter to the river, or in the reverse direction. The clogged surface over those beds which require cleaning is then scraped with shovels. The scrapings are carried by wheelbarrows to the driveway, the surface is raked and smoothed, and the filter again put in service. Later, the dirty sand left upon the driveway is removed to a bank near the washer, from which, after washing, it is dumped over a paved slope, the foot of which extends to the lower driveway, ready for replacing upon the filter at the time of sanding. This work constitutes the general routine at the filter, but it is constantly interrupted during the winter season by the ever-recurring necessity of removing snow and ice from the filter surface. The ice is never allowed to become so thick that it will touch the sand surface during high water upon the filter, and it is either cut and thrown out, or large fields floated away from such beds as need scraping.

For purposes of reference the beds of the filter are numbered from 1 to 25, beginning at the westerly end.

Quantitative Results.—The amount of water pumped, and thus the amount filtered, has been dependent upon the demands of the city's use, as shown by the draft upon the reservoir. Whenever the surface of the filter is not excessively clogged, the yield is generally constant, and the rate about 5 000 000 galls. per day, the required quantity being obtained by running the pumps the necessary number of hours. As frequently some time is lost between stopping the low and starting the high-service pumps, and *vice versa*, and also because the filter is often out of service for scraping or similar requirements,

there are long intervals when there is almost constant need of pumping continuously, except occasionally upon Sundays.

TABLE No. 4.—AVERAGE DAILY QUANTITY OF WATER PUMPED, IN MILLIONS OF GALLONS, AND AVERAGE HOURS OF PUMPING PER DAY, AT LAWRENCE, MASS., FOR EACH MONTH, 1893–1900.

Month.	1893.		1894.		1895.		1896.		1897.		1898.		1899.		1900.	
	Quantity.	Hours per day.	Quantity.	Hours per day.	Quantity.	Hours per day.	Quantity.	Hours per day.	Quantity.	Hours per day.	Quantity.	Hours per day.	Quantity.	Hours per day.	Quantity.	Hours per day.
January	4.0	20.2	2.9	15.0	2.9	15.6	3.1	16.2	3.4	18.9	3.4	25.2	3.2	19.3	3.3	22.1
February	3.7	18.6	2.8	17.0	3.0	16.9	3.1	16.8	3.1	23.7	3.1	20.3	3.3	19.3	3.3	24.6
March	3.2	16.3	2.7	14.6	2.9	18.0	2.8	17.4	2.6	18.0	3.4	28.2	3.0	21.0	3.4	25.3
April	2.7	13.5	2.4	13.2	2.6	16.1	2.8	15.6	2.8	21.2	3.3	19.6	3.0	19.2	3.0	33.9
May	2.9	15.2	2.8	14.2	2.8	14.9	3.2	17.7	2.9	21.7	2.9	17.5	3.2	19.7	3.2	29.5
June	3.0	16.1	3.0	15.8	3.1	16.8	3.2	17.3	3.0	17.8	3.3	26.7	3.5	21.4	3.6	23.1
July	3.0	15.8	3.0	15.3	2.9	15.3	3.1	16.3	3.4	20.1	3.3	29.8	3.5	20.5	3.7	22.9
August	2.6	13.8	2.8	14.2	2.8	15.1	3.0	15.6	3.1	18.1	3.2	21.5	3.3	18.0	3.6	20.8
September	2.8	14.7	2.6	13.7	2.9	15.1	3.2	16.7	3.3	18.7	3.8	22.7	3.5	19.8	3.5	22.4
October	2.7	13.9	2.7	13.8	2.8	15.0	2.8	15.4	3.2	19.1	3.5	23.7	3.1	18.8	3.3	19.9
November	2.6	13.6	2.6	13.8	2.7	14.9	2.8	15.6	3.1	19.8	3.7	23.6	3.0	19.2	3.0	18.1
December	2.7	13.9	2.5	13.4	2.7	14.0	3.0	15.7	3.1	22.3	3.0	17.9	3.0	19.5	2.9	18.0
Average	3.0	15.5	2.7	14.5	2.8	15.6	3.0	16.4	3.1	19.9	3.3	23.9	3.2	19.6	3.3	23.4

NOTES.—The high-service pump was put into service in December, 1896, and since that date the quantities include the water used in both low and high service.

The average hours of pumping are based upon the total for each month divided by the total number of days, and, after 1896, include the time for both the high and low-service engines.

In order to present this information in comprehensive form, there is given in Table No. 4 the average daily consumption by months (both high and low-service being included, since 1896), and the average number of hours per day during which the pumps were operated. The hours of pumping per day represent the totals per month divided by the total number of days, and, since 1896, is given as the sum of the hours of operation of both the high and low-service pumps. With the exception of portions of the years 1898 and 1900, when a small-capacity, low-duty pump was used for some of the time upon the high service, and which of necessity was run very often when the low-service engine was in operation, the hours given represent quite closely the time during which it was necessary to operate the filter.

The relation of temperature to the consumption of water is so intimate that it has been deemed advisable to present in Table No. 5 statistics of the temperature of the air at Lawrence during the past eight years. These records were obtained from the reports of the

United States Weather Bureau, and are the results of observations made by the Essex Company at a station located on the north side of the Merrimac River near the dam, in an unexposed but not particularly well-sheltered place.

TABLE No. 5.—AVERAGE MONTHLY TEMPERATURE OF AIR AT LAWRENCE, MASS., ALSO THE MAXIMUM AND MINIMUM FOR EACH MONTH, 1893–1900.

Months.	1893.			1894.			1895.			1896.			1897.			1898.			1899.			1900.		
	Aver.	Max.	Min.	Aver.	Max.	Min.	Aver.	Max.	Min.	Aver.	Max.	Min.	Aver.	Max.	Min.	Aver.	Max.	Min.	Aver.	Max.	Min.	Aver.	Max.	Min.
January....	17	51	—11	26	53	— 2	22	45	— 3	21	42	—14	25	56	— 3	25	51	—13	25	55	— 9	26	54	—13
February..	24	52	— 5	22	49	—12	19	46	—11	26	54	—15	27	51	— 5	28	57	—19	23	51	—14	27	59	— 5
March.....	32	54	5	40	74	15	32	49	7	30	60	8	34	58	0	40	64	18	32	59	11	31	56	5
April.....	44	70	21	47	77	17	45	76	22	48	87	22	48	84	17	43	72	19	46	83	25	45	80	19
May.....	57	87	34	59	85	34	61	94	30	62	96	33	58	85	34	57	84	33	58	90	32	54	93	28
June.....	66	92	50	69	93	44	70	95	46	67	96	46	62	91	44	66	91	45	69	93	49	68	92	39
July.....	71	90	52	74	97	53	70	92	52	73	93	52	75	100	52	72	97	50	72	92	50	73	95	47
August....	69	90	48	69	89	47	71	94	46	71	97	47	71	90	54	72	91	50	69	90	49	70	96	49
September.	59	81	39	65	86	39	64	94	39	61	86	37	62	94	38	65	91	41	61	82	37	64	90	38
October....	54	77	26	52	74	34	47	69	22	48	72	27	53	86	26	53	82	31	53	77	28	55	83	26
November..	39	63	12	35	60	10	42	73	15	42	71	16	38	66	8	40	61	18	39	63	21	42	70	14
December .	26	53	—10	27	49	— 2	31	61	4	25	52	— 4	31	60	0	27	54	—14	32	63	2	29	56	2
Average ...	46	..	....	49	..	....	48	..	....	48	..	....	49	..	....	49	..	....	48	..	....	49	..	....
Maximum ..	..	92	....	..	97	....	..	95	....	..	97	....	..	100	....	..	97	....	..	93	....	..	96	....
Minimum ..	..	..	—11	..	..	—12	..	..	—11	..	..	—15	..	..	— 5	..	..	—19	..	..	—14	..	..	—13

NOTE.—All data in this table are compiled from the records of the United States Weather Bureau.

Quantities Between Scrapings.—The importance of these data in regard to any filter is generally recognized, but in this particular case, owing to the exigencies of operation, the information is less definite and valuable than it would be if the yield from single beds was measured. In the case at hand, while at the time of scraping the whole surface is necessarily drained, different beds may be and usually are cleaned each time, also the same order of scraping the beds is rarely observed twice in succession.

It has been possible to select a few cases where the whole area of 25 beds was completely scraped in 1 or 2 days, and when no scraping occurred on intermediate dates. These results, representing the longest periods and greatest quantities passing through the 2.36 acres of filtering surface between two successive complete scrapings, are given in Table No. 6. The table also indicates that in actual practice the filter has not been operated during recent years more than a month without cleaning, and, generally, the period has been less.

TABLE No. 6.—LONGEST PERIODS BETWEEN COMPLETE SCRAPINGS OF THE LAWRENCE FILTER FOR THE YEARS 1893–1900.

Number.	Last day of a complete scraping.	First day of next complete scraping.	Length of period, in days.	Total quantity between scrapings, in millions of gallons.
1	March 26th, 1898	April 27th, 1898	32	109
2	April 28th, "	May 27th, "	29	90
3	May 28th, "	June 23d, "	26	80
4	June 24th, "	July 14th, "	20	74
5	July 15th, "	August 9th, "	25	85
6	August 11th, "	" 30th, "	19	67
7	" 31st, "	September 22d, "	22	85
8	April 6th, 1899	April 26th, 1899	20	71
8	June 14th, "	July 6th, "	22	78
10	July 7th, "	" 20th, "	13	49
11	April 18th, 1901	May 30th, 1901	41	121

Record of Scrapings.—There is a lack of definite data in regard to the exact dates of scraping prior to the spring of 1895, and of the dates and amount of sanding prior to 1897. Information has been culled from various sources, such as the regular scraping record books, time books, pumping station records, diaries, miscellaneous note books, etc., and it is believed that the following statements and tables contain as exact information as will likely ever be obtained.

It appears that, after starting the filter upon September 20th, 1893, the whole surface was scraped twice before December 1st. Apparently, the filter was not cleaned again until the next spring. The work began about the middle of March and was completed about the middle of April. The surface was again scraped during the latter part of the month of July. The best evidence goes to show that the entire filter was again cleaned between the latter part of August and the early part of October. The whole surface was again gone over during the last half of the month of November. To summarize, it will be seen that the filter was scraped four times during the year 1894, although it is possible that a few of the beds at the upstream end were scraped at another time, of which there is no memorandum.

The record for the first three months of 1895 is somewhat indefinite, but it is believed that there is sufficient information to warrant including the record for the year in the tables. The data for each of the years 1895 to 1900 are given in Tables Nos. 7 and 8, in the form of total number of times of scraping for each bed and totals for each

month. Occasionally, beds have been cleaned in portions, or at flat ends only, but each such scraping is given the proper fractional weight in making up the totals, the latter being recorded in each case, however, to the nearest unit.

TABLE No. 7.—Record of Scrapings of the Lawrence Filter, Arranged by Beds for each Year, 1895–1900.

Beds.	1895.	1896.	1897.	1898.	1899.	1900.
1	15	16	17	14	17	16
2	16	17	17	14	17	16
3	16	17	18	14	17	16
4	16	16	19	14	16	16
5	16	16	19	14	16	16
6	16	15	18	14	16	15
7	17	16	18	14	16	16
8	17	14	16	14	16	16
9	16	14	16	15	15	16
10	16	14	16	15	17	16
11	13	13	17	15	16	17
12	14	13	18	15	18	18
13	14	12	18	15	18	16
14	13	11	18	14	19	16
15	13	10	17	12	19	14
16	13	11	16	13	19	15
17	13	10	16	13	19	15
18	13	10	16	12	17	15
19	12	11	17	11	16	16
20	12	10	16	12	16	16
21	11	9	14	13	17	16
22	11	8	15	12	17	16
23	11	7	14	10	16	16
24	10	7	15	10	16	15
25	10	7	15	12	15	15
Totals	344	304	416	331	421	395
Averages	14	12	17	13	17	16

TABLE No. 8.—Record of Scrapings of the Lawrence Filter, Arranged by Months for the Years 1895–1900.

Months.	1895.	1896.	1897.	1898.	1899.	1900.
January	20	9	20	17	25	25
February	20	20	34	22	12	25
March	20	43	46	34	6	25
April	27	31	50	25	49	33
May	30	31	25	25	26	47
June	25	18	25	25	30	27
July	29	32	39	25	50	40
August	31	24	32	47	46	35
September	25	20	27	28	31	48
October	39	16	32	40	43	26
November	53	46	53	25	53	39
December	25	14	33	18	50	25
Totals	344	304	416	331	421	395
Averages	29	25	35	28	35	33

Record of Sandings.—The first sanding of the filter was done after some of the scrapings in 1894, and, as the washing machine for cleansing dirty sand was not installed until the summer of 1895, it is probable that unused sand, obtained during construction, and an additional amount hauled from Gale's Hill, was used during these years. That replaced in 1896 and thereafter was, for the most part, washed sand, which had been removed from the filter surface, and the sanding was done in bulk.

In 1897 the first record of the dates of sanding appears, together with the depths replaced at the crowns of the beds, the sides being filled slightly to bring them to the level of the lateral carriers. The depths of sandings of each bed at the crown for the years 1897, 1899 and 1900 are given in Table No. 9.

TABLE No. 9.—Depth of Sand in Inches Replaced at the Crown of each Bed of the Lawrence Filter for the Years 1897, 1899 and 1900.

Beds.	1897.	1899.	1900.
1	13.6	11.9	9.8
2	13.6	14.0	10.6
3	13.0	12.9	12.0
4	16.0	25.8	12.7
5	15.4	22.5	12.0
6	15.4	21.5	12.5
7	15.2	21.8	11.0
8	12.5	34.2	10.8
9	15.1	24.0	12.0
10	10.5	25.2	11.9
11	10.0	20.8	11.4
12	11.1	18.0	9.5
13	10.7	15.0	13.5
14	10.9	15.5	13.5
15	9.9	11.5	18.3
16	10.2	12.0	18.5
17	9.2	9.1	16.5
18	11.3	12.0	15.3
19	9.5	9.2	15.0
20	9.3	15.4	22.2
21	8.7	9.5	15.0
22	8.4	9.8	18.3
23	9.5	16.0	25.0
24	8.2	15.9	24.0
25	9.5	14.0	18.0
Averages	11.5	16.3	14.8

In 1898 extensive experiments were made during the summer months, and the latter portion of the year was occupied in the repair work on the underdrains in certain beds, so that very little sanding was done.

Beds Nos. 1, 2, 3 and 12 were filled to a depth of about 13 ins., and the beds repaired (Nos. 13 to 22, excepting No. 20) were brought to original grade.

From the summaries in the tables it will be seen that, on an average, each bed has been scraped about 15 times per year, and because the average of depths of sand replaced at the crowns is equivalent to about three-fourths of this amount over the entire filter area, the average depth removed at each scraping has been practically $\frac{3}{4}$ in. The average depth replaced at the crowns, in 1899 and 1900, was $15\frac{1}{2}$ ins., equivalent to a depth of $11\frac{1}{2}$ ins. over the whole surface, or a total of about 3 500 cu. yds.; which figure agrees approximately with rough measurements of the amount of material removed and replaced each year.

Loss of Head.—The loss of head is the difference between the level of the water on the filter surface and that of the surface of the water in the pump-well, the latter elevation being indicated by a counterweight sliding on a graduated rod in the engine-room above and showing the position of the float below, referred to the datum of levels. Formerly, the elevation of the water on the filter was read directly upon a gauge board, but within recent years it also has been indicated by the position of a counterweight moved by a float and sliding along a scale board in the gate-house.

The bottom of the pump-well is at Elevation 26, and the bottoms of the outlets of the underdrains in the filter are at Elevation 29; thus it is evident that the difference of the two levels mentioned above indicates an incorrect loss of head whenever the water in the pump-well is drained below Elevation 29. Prior to September, 1898, the losses of head were frequently recorded greater than could have been possible. It is probable that, because of this drawing down, air was admitted backward into the underdrains, and a greater resistance was occasioned than would have occurred if the water in the pump-well had been kept above Elevation 29. However, in compiling the data in Table No. 10, the maximum possible loss of head was assumed to have been that which would have obtained with the water at Elevation 29 as it passed out of the underdrains.

Table No. 10 contains a statement of the average losses of head by months, for the seven complete years of operation; together with the average speed of the pumps and the average temperature of the river water as applied to the filter.

TABLE No. 10.—AVERAGE LOSS OF HEAD IN FEET IN THE LAWRENCE FILTER, BY MONTHS, FOR THE YEARS 1894–1900; ALSO AVERAGE REVOLUTIONS OF THE LOW-SERVICE PUMP PER MINUTE AND THE AVERAGE TEMPERATURE OF THE RIVER WATER IN DEGREES FAHRENHEIT.

Months.	1894.			1895.			1896.			1897.			1898.			1899.			1900.		
	Loss.	Rev.	Temp.	Loss.	Rev.	Temp.	Loss.	Rev.	Temp.	Loss.	Rev.	Temp.	Loss.	Rev.	Temp.	Loss.	Rev.	Temp.	Loss.	Rev.	Temp.
January...	3.1	16	32	6.2	15	32	5.8	15	34	7.2	15	32	8.0	13	32	4.4	15	33	6.0	13	33
February.	6.0	14	32	6.9	15	32	5.9	16	34	7.5	13	32	8.0	10	33	4.6	15	33	6.2	13	33
March.....	5.4	15	38	7.6	13	32	7.2	14	35	7.6	13	33	7.7	12	38	5.5	12	33	6.0	14	34
April.....	4.2	15	48	7.1	13	43	5.8	15	46	6.9	14	45	5.8	15	45	5.0	14	41	5.7	14	44
May.....	5.0	16	58	5.5	15	61	5.6	15	63	4.9	16	60	6.1	15	57	4.3	14	59	5.3	14	56
June.....	4.6	15	69	5.0	16	73	5.2	15	69	5.0	16	65	4.5	15	70	3.6	15	73	3.8	15	72
July.....	3.3	16	78	4.4	16	74	3.6	16	77	5.0	16	74	4.7	16	77	3.6	15	77	3.9	15	78
August...	3.6	16	75	4.4	16	74	3.2	16	77	5.2	15	73	5.5	14	76	3.7	16	75	3.7	15	77
September	4.1	16	72	3.4	16	68	3.8	16	68	5.0	16	68	4.6	15	70	3.6	16	68	3.7	15	72
October...	4.5	16	56	5.5	15	50	5.4	15	52	5.5	16	57	4.9	13	58	4.0	15	57	4.0	15	61
November	5.8	16	40	5.8	15	42	6.3	15	42	6.9	14	42	5.7	14	42	4.6	14	42	4.4	15	46
December.	5.9	16	32	5.3	16	35	6.1	15	33	7.3	13	34	4.7	15	33	5.1	14	36	5.1	15	34
Yearly average..	4.7	15.6	52	5.6	15.1	51	5.3	15.3	52	6.2	14.8	51	5.9	13.9	53	4.3	14.6	52	4.8	14.4	53
Average, Dec.-Mar.	4.8	....	34	6.6	....	32	6.0	....	35	7.1	....	33	7.7	....	34	4.8	....	33	5.8	....	34
Average, Jun.-Sep.	3.9	....	74	4.3	....	72	3.9	....	73	5.0	....	70	4.8	....	73	3.6	....	73	3.8	....	75
Maximum	7.7	....	..	8.0	....	80	8.0	....	84	8.5	....	82	8.5	....	82	6.8	....	80	6.7	....	82
Minimum.	1.8	....	32	2.6	....	32	2.7	....	32	3.2	....	32	2.4	....	32	2.5	....	32	3.1	....	32

NOTE.—Prior to May, 1897, the records do not show the elevation of water in pump-well when pumping. For those days during this time, when the loss of head is greater than 7.0 ft., and for those days afterwards when the water in the pump-well is below Elevation 29.00, the maximum is assumed to be the difference between the elevation of the water on the filter surface and Elevation 29.00.

The table exhibits clearly the greater loss of head under which the filter has been operated during cold weather, and the fact that, even with the maximum possible head, the rate of pumping was necessarily reduced, especially during the winter of 1897–98.. The relative improvement in these factors during 1899–1900 is also noticeable.

Effect of Scraping upon Quantitative Efficiency.—It is customary to scrape a filter when the amount of water which comes through with the maximum loss of head has diminished below that required, and it is expected that with a clean surface the normal quantity will be obtained with a smaller head than before, but at Lawrence this result has not always been attained. Occasionally, it has seemed that air has been caught in the body of the filter when refilling, and its presence has

TABLE No. 11.—Effect of Scraping Five or More Beds of the Lawrence Filter, as shown by the Change in the Loss of Head.

Date of scraping.	Beds Scraped.		Average Loss of Head For Four Days.*		Percentage. Gain in loss of head.
	Number.	Designation.	Before scraping.	After scraping. (Adjusted.)	
(1)	(2)	(3)	(4)	(5)	(6)
1895.					
June 19	10	1-10	6.8	4.4	35
June 26-27	15	11-25	4.0	4.4	—†
July 16-18	15	11-25	4.4	4.2	5
September 10-12	17	9-25	3.3	3.0	9
1896.					
April 8-10	25	1-25	5.3	6.8	—
May 27-29	15	5-12, 17-23	6.4	4.6	28
June 6-8	14	1-14	4.9	3.3	33
August 14	8	1-8	3.6	2.8	22
November 10-13	19	1-10, 16-24	6.5	5.5	15
November 24-25	16	10-25	6.2	6.2	—
December 10	9	1-9	6.1	6.3	—
December 31	5	6-10	6.0	6.8	—
1897.					
May 5-6	11	15-25	4.9	5.2	—
May 19	6	1-6	4.9	4.7	4
May 28	8	7-14	3.8	5.3	—
June 22-25	21	5-25	6.5	4.6	29
July 12-14	17	1-17	5.1	3.8	25
August 17-19	14	1-8, 20-25	5.8	5.4	7
August 25-27	11	9-19	5.1	6.1	—
September 15-16	12	5-16	4.9	4.5	8
October 5-7	10	1-10	5.8	6.1	—
October 13-14	15	11-25	5.4	4.8	11
October 26-28	7	1-7	4.1	6.6	—
November 10-11	16	10-25	7.0	6.8	3
December 1-2	6	10-15	7.0	6.7	4
December 11-14	25	1-25	7.0	7.2	—
1898.					
February 26	9	1-9	8.0	8.5	—
March 25-26	23	1-22, 25	7.9	7.0	11
April 27-28	25	1-25	6.3	8.3	—
May 27-28	25	1-25	7.0	7.6	—
June 23-24	25	1-25	4.6	4.4	4
July 14-15	25	1-25	5.3	6.0	—
August 9-11	25	1-25	7.0	2.4	66
August 30-31	22	1-22	6.8	3.2	53
September 22	13	1-13	5.0	3.2	36
September 27	12	14-25	5.0	4.2	16
October 10-11	20	(1-18), (19-25)½	4.9	4.3	12
November 15-18	25	1-25	6.1	3.6	41
1899.					
January 4-6	7	15-17, 22-25	4.4	6.9	—
February 21-24	8	15-22	4.9	3.8	22
April 5-6	25	1-25	6.0	1.8	70
April 26-28	25	1-25	4.9	3.5	29
May 23-25	11	15-25	4.7	3.7	21
June 13-14	25	1-25	4.8	1.9	60
July 6-7	25	1-25	5.1	2.0	61
September 14	13	6-18	3.7	3.1	16
September 28	6	1-3, 6, 19, 20	3.6	4.1	—
December 16-19	25	1-25	4.9	5.6	—
1900.					
January 10	10	1-10	5.8	1.8	69
January 16	6	11-16	6.0	4.5	25
January 20	9	17-25	6.5	5.5	15
February 1	5	1-5	6.7	4.8	28
April 12-13	21	1-21	6.2	6.9	—
April 25	8	1-8	5.8	5.7	2

*In a few cases, where three days, only, elapsed between successive scrapings, the data for three days before and after scraping have been included in the table.

† A dash designates a loss rather than a gain.

TABLE No. 11—(*Continued*).

(1)	(2)	(3)	(4)	(5)	(6)
May 1	8	9–16	5.5	5.0	9
May 25	13	10–22	5.8	3.5	40
June 7–9	14	1–12, 22, 23	4.6	3.7	20
June 27	12	13–21, 23–25	4.0	3.3	18
July 6	12	1–12	4.0	4.4	—*
July 16	12	13–20, 22–25	5.0	4.0	20
July 27	12	1–12	3.8	2.6	32
August 7	9	12–14, 19–20, 22–25	4.1	4.2	—
August 16–17	12	1–12	3.7	3.5	5
August 28–30	8	12, 13, 17–20, 22, 23	3.8	4.1	—
September 5–6	14	1–9, 11, 16, 21, 24, 25	3.9	3.6	8
September 14	13	10–20, 22–23	4.0	3.2	20
September 18	12	1–9, 21, 24, 25	3.6	3.4	6
September 25–26	9	14–22	3.4	4.3	—
October 11, 12	5	7, 11–13, 23	4.0	3.4	15
October 18	5	1–5	4.3	4.0	7
October 23–25	11	14–22, 24, 25	4.9	4.2	14
November 13	5	3–4, 22–25	4.2	3.5	17
November 20–21	20	1, 2, 5–21, 23	4.9	3.8	22
December 7–8	22	1–21, 25	5.2	6.0	—

* A dash designates a loss rather than a gain.

caused an increased loss of head until it has escaped. Winter disturbances have at times produced such effects that scraping of the surface has not increased the quantity filtered; moreover, the yield of certain beds, which have recently been repaired, was not increased appreciably by scraping, prior to reconstruction.

Table No. 11 has been prepared from the filter records, in order to show the actual conditions of yield, expressed as average losses of head, during periods of 4 days directly before and after scraping. These data have been tabulated only for such times as when at least 5 beds were scraped and there was no interference in the conditions, due to cleaning, during the 4 days before and after. The number and designation of the beds scraped is entered with the dates. The actual average loss of head is given for the 4 days prior to cleaning, and that for the same period afterward has been obtained by adjusting the actual average to the rate of filtration and temperature of the water before scraping. For the years 1895 and 1896, the losses are not adjusted for rates, on account of insufficient data, but it has been assumed that these are the same before and after scraping, which supposition the results of other years have shown to be not seriously in error.

It will be noticed that the improvement in cold weather is less than at other seasons, and, at times, it appears that the loss of head was even greater after scraping than before. This condition was probably pro-

duced by entrained air caught in the filter when refilling, the effect of which is more evident with the low-temperature conditions of winter. Also, certain of the summer records occasionally show losses which cannot be accounted for in any other way than by the presence of air in the filter. It is known that the desire to return the filter to service quickly has often caused too rapid filling and subsequent starting of the pumps. During 1898 Mr. Walter E. Spear studied the effects of rapid refilling, and pointed out clearly, as shown in a diagram published in the report of the Lawrence Water Board for that year, that hastened refilling oftentimes lessened the yield of the filter for a few days.

The difficulty caused by entrained air can be remedied by back-filling from below, filtered water entering through the underdrains and passing upward through the sand to a proper elevation before turning on the supply of raw water; by which method the air will be forced out of the bed. Care must be observed, however, not to back-fill so rapidly as to disturb the sand about the underdrains, but this danger can be wholly avoided by providing a back-filling pipe capable of being so regulated that not more than the maximum permissible rate of refilling can take place under the existing pressure conditions.

It is also noticeable that, since the early operation of the filter, the greatest benefit from cleaning the surface was secured during the last two years; this undoubtedly was due to the more thorough and careful management under which the filter has recently been operated.

Intermittence of Operation.—It was intended, when the filter was built, that it should be operated intermittently, or, in other words, that there should be a daily period of rest, during which the water in the bed would be drawn out and the sand filled with air to the bottom. This condition was regarded as necessary to insure the "burning up" of the organic matter retained in the filter.

It was endeavored to give the filter this daily rest during its early history, but various circumstances, such as the demands of consumption and the securing of equally favorable results with continuous operation, has led, especially in recent years, to practically continuous filtration, except during times of scraping. From Table No. 4 the average number of hours per day during which the pumps were not operated may be determined; and, realizing that at least 3 hours should elapse between turning on the water and starting the pumps, it will be

seen that during recent years there has been but little opportunity to fill the sand with air. The record of drainings is given in Table No. 12.

TABLE No. 12.—Number of Times when the Lawrence Filter was Drained, from 1894 to 1900, Inclusive.

Months.	1894.	1895.	1896.	1897.	1898.	1899.	1900.
January	17	16	6	7	6	14	4
February	15	8	9	11	4	8	6
March	30	10	9	12	5	7	6
April	23	13	13	10	9	5	9
May	26	19	12	9	13	12	8
June	26	15	14	14	8	11	6
July	16	23	17	12	10	10	9
August	27	20	19	15	9	14	12
September	22	15	22	12	5	12	8
October	22	19	16	13	4	14	13
November	24	15	13	13	5	12	6
December	17	10	4	8	13	12	3
Total	265	183	154	136	91	131	90
Average per month.	22	15	13	11	8	11	8

Cost of Additional Construction, and Expense of Maintenance.

Additional Construction Items.—Since placing the filter in service, September 20th, 1893, there have been additional accounts which might properly be charged to construction. These expenditures include the purchase of machines to aid in the work of maintenance, the building of a new driveway by which the cost of conveying has been reduced, and the paving of the sloping bank, thus enlarging and improving the storage place for washed sand. The original cost of the filter, as given in the Report of the Water Board for the year 1893, was $65 459.67. The additional items, expressed in rounded figures, are given in Table No. 13.

TABLE No. 13.—Additional Construction.

1894.	Labor and material, as per Report of Water Board	$4 070
1895.	Cost of washer, including concrete work	540
	Labor account given in Annual Report, minus that which is properly chargeable to maintenance	2 700
1896.	Cost of ice elevator and conveyer	2 730
1899.	New driveway and paving of storage slope	3 600
1900.	" " " " "	1 240
		$14 880

These additional items, together with the original cost, make the total expenditure for construction about $80 000.

Cost of Maintenance.—One of the most interesting elements of a study of the Lawrence filter has been the annual cost of the several operations. Various figures appearing in early reports of the Water Board have been misleading, because they have included expenses of grading, care of grounds, etc., which, in accordance with the usual custom of charging such special and unclassified items to some main account, burdened the filter charges. This circumstance originated from the desire to have constantly at hand (for expeditious cleaning of the filter, etc.) an ample laboring force, which was employed upon odd jobs whenever there was not sufficient routine work.

The writers believe that the data of expense presented in the following tables are as nearly correct as can be obtained at this date, because of the length of time which has elapsed since the first record. In order to render the figures as reliable as possible, a study and a transcript of all important records were made, together with a comparison of the timekeeper's weekly report, with the daily timebooks, and finally both of these were compared with the filter record books, showing the extent and nature of the work of maintenance for each day. Notwithstanding the degree of care exercised in the following compilations, the insufficiency of some of the data has made it seem advisable to round up all figures of cost, a process which it is believed will also simplify comparison.

TABLE No. 14.—ITEMIZED STATEMENT OF COST OF MAINTENANCE OF THE LAWRENCE FILTER, FOR THE YEARS 1895-1900.

Items.	1895.	1896.	1897.	1898.	1899.	1900.
Scraping	$2 550	$1 350	$1 950	$1 930	$2 060	$2 130
Scraping and sanding		1 460	840	300	1 270	1 250
Conveying	1 320	1 180	2 200	1 660	1 470	1 410
Washing	1 000	2 120	1 950	1 600	1 450	1 510
Removal of snow and ice	2 780	2 350	2 330	3 480	2 300	2 330
General	450	490	850	710	500	720
Total	$8 100	$8 950	$10 120	$9 680	$9 050	$9 350
Per million gallons	7.80	8.10	9.00	8.00	7.70	7.70
Total, minus snow and ice	5 320	6 600	7 790	6 200	6 750	7 020
Per million gallons	5.10	6.00	6.90	5.10	5.80	5.80
Special repairs	.....	.....	.....	4 830	.....	2 260
Total pumpage for year in million gallons	1 040	1 100	1 130	1 210	1 170	1 210

NOTE.—The writers were unable to classify the cost of maintenance during the period of operation of the filter in 1893 and during 1894. The total expenditures for this purpose during 1893 (3½ months) amounted to $1 210, and in 1894 to $4 610.

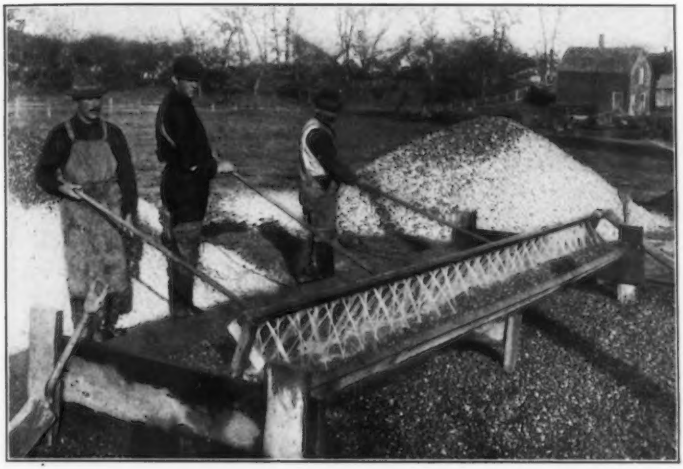


FIG. 1.—METHOD OF WASHING GRAVEL.

FIG. 2.—WHEELING OUT SAND, AFTER SCRAPING, LAWRENCE CITY FILTER.

Classification of Accounts.—In explanation of the items in Table No. 14, the following statements are made to show the nature and extent of the work done under each classification.

1.—Scraping, includes the removal of the surface layer of dirty sand by means of shovels and throwing into small piles, about 10 to 12 ft. apart, upon the surface of the bed; together with wheeling the sand from these heaps to a temporary dump along the lower driveway on the north side of the filter. This process also includes raking and smoothing the beds after cleaning.

2.—Sanding, includes removing the clean sand from the storage bank along the driveway to the surface of the bed being sanded, distributing it in layers, and smoothing the surface. The cost of sanding includes the expense of the scraping necessary to prepare the surface of the filter beds for this operation.

3.—Conveying, includes the loading of the dirty sand and its transportation in carts from the temporary dump on the lower driveway to a permanent dump close to the washer. During the early years, before the bank of clean sand was placed as advantageously as at present along the paved slope to the driveway, this item also included the loading and transportation from the dump of clean sand to temporary piles along the lower driveway, close to the beds on which it was to be used for sanding.

4.—Washing, includes the screening of the dirty sand at the first or traveling hopper of the washer and the transportation from the draining boxes to the permanent storage bank, together with such attention and repairs as the washer itself requires.

5.—Removal of snow and ice, includes, for snow, the loading and transportation from the frozen filter surface in carts or sleds to the river bank. For ice, the item includes cutting and moving cakes to the ice-conveyer, feeding the same and taking care of the delivery over the river bank, together with the cost of coal and such attention as the machinery demands. This last account also includes, during the early history of the filter, and, to a much less extent, at the present time, the loading and transportation of ice in carts or sleds from the filter surface.

6.—General, includes miscellaneous items not appearing in the foregoing classification, such as care of filter banks and lawn directly adjacent, repairing and cleaning main distribution channel and lateral

carriers, and repairs to driveway and paved bank. All repairs of tools and machinery are charged to the proper accounts of the work upon which they are used. The expenditures under this item are not constant, but fluctuate according to the amount of repair work necessary each year.

Detailed Study of Scraping.—It has been the custom, when it was the intention to scrape a portion of the filter upon a given day, to shut off the inlet water during the evening before, and, by running the pumps at gradually reduced speed, drain the sand so that men could work upon it the next morning. Since January, 1900, however, water has been pumped from the surface of the filter back to the river when draining. Thus, it has not been necessary to close the inlet gate as early as formerly, or to have so much of the work done in an uneconomical manner by the large pump in the station. But the effect, which is of greater importance, is that the filter surface can now be made ready for cleaning at a definite time, whereas, previously, because of the uncertainty of draining through a more or less clogged material, the filter was frequently not in a condition for work when desired.

Laborers first scrape the surface, removing the *schmutzdecke*, varying from ½ to 1 in. in thickness. Sandals are not worn on this work, as is customary at some other plants. When a few beds only are cleaned, this part of the work is usually entirely completed before removing any of the sand; but if a large area is being scraped, the two operations are often performed alternately. Until recently the usual shovels with short handles and square mouths have been used, but at the present time special long-handled shovels of extra width have been tried with success and economy.

The wheeling-out is done in barrows upon planks laid upon the sand surface, and the length of carry varies from 75 to 150 ft. This work is shown in Fig. 2, Plate IX. The surface of the bed compacted by the process of cleaning is then made porous or loose by the use of rakes with teeth about 2 ins. long, and, finally, the raw surface is evened with a thin smoother attached to a handle and used like a rake. For some time between 1895 and 1899 special rakes, with teeth about 6 ins. long, were used to loosen the upper portion of the sand after scraping. That this process permitted the water to pass through the sand more freely is probably true, but it undoubtedly tended also to produce each time a

deeper clogging in the sand. It is therefore believed that it was a prudent measure to abandon their use in favor of the short-toothed rakes, which are entirely sufficient to loosen the surface of the sand compacted by the laborers in working without sandals during scraping.

Unfortunately for the purpose of comparison, the cost of scraping has not always borne an exact relation to the amount of work performed. This has been largely due to the uneconomical methods used, some of which will necessarily obtain until greater expenditures for construction and equipment are allowed. Whenever a few beds only are scraped, the work is performed by the usual maintenance force always at the plant, varying in number from 8 to 15 men. At times, when the demand for water renders it necessary to scrape a large part of the whole surface at once, additional laborers are drafted from the street and pipe repair force. As many as 30 men have at times been used, many of whom were unfamiliar with the best methods of performing this kind of work. This extravagant method of cleaning has been used somewhat frequently, and is a result of the necessity of scraping as large a unit area as possible at one time. A few years since, one of the writers of this paper prepared a statement of the amount of work accomplished with varying numbers of men employed, showing quite conclusively that 10 men was the most economical number to use during scraping as then carried on, because larger numbers caused some to be in the way of others.

Table No. 15 presents a summarized statement of the cost of scraping in comparison with the amount of work done.

TABLE No. 15.—STATEMENT OF THE TOTAL NUMBER OF BEDS SCRAPED PER YEAR, TOGETHER WITH THE COST PER BED PER SCRAPING, AND PER MILLION GALLONS FILTERED.

Years.	Number of bed scrapings.	Cost of scraping.	Cost per bed.	Cost per million gallons of water filtered.
1896	304	$1 350	$4.40	$1.20
1897	416	1 950	4.70	1.70
1898	331	1 930	5.80	1.60
1899	421	2 060	4.90	1.80
1900	395	2 130	5.40	1.80

Some recent studies show that the costs in Table No. 15 are divided among the several items about as follows: Wheeling out, $\frac{1}{2}$; scraping,

$\frac{1}{3}$; and smoothing of surface, $\frac{1}{6}$ of the total. These figures show at once in what portion of the work a saving should and can be made, namely, in the use of some approved form of conveyer to replace the wheel-barrow. The scraping of single beds has occasionally cost somewhat less than $3, although in cold weather, with a frozen sand surface, the cost has been as high as $10 per bed.

Detailed Study of Sanding.—This process requires but a short description. In the early history of operations, all the conveying charged to this item was done with wheel-barrows; but, recently, it has been the custom to place, over the bed to be sanded, a platform, level with the lower driveway, upon which the teams deliver the clean sand and from which it is wheeled to position by barrows. The method of sanding is about as follows: The bed is scraped as usual, the upper 10 ins. is removed and placed at one side, then such an amount of clean sand is used in the excavated trench as will bring the bed to grade when the old sand is replaced upon it, and the surface shaped and smoothed.

It is probable that but little sanding was done in 1895, and, in consequence, the amount of work required in 1896 was considerably increased. For this reason, and also because less economical methods were used than later, the cost of sanding during this year was unusually high. The reduced cost in 1897 may be explained in part by the fact that a less depth of sand was added during this year, and also, perhaps, because certain expenditures classed under "Conveying" should rightfully be charged to this work. The figures in 1898 include simply the cost of sanding Beds Nos. 1, 2, 3 and 12.

It appears from the records of the years 1899 and 1900 that the average cost of sanding a bed is about $50. It has been found that on the average the number of scrapings per bed per year (1896–1900) has been about 15, and the average cost of each about $5.00, making $75 approximately the total annual cost of keeping a bed clean. From this figure the economy of bringing the beds to grade by sanding once a year is readily apparent.

Detailed Study of Conveying.—The statistics for conveying are less satisfactory than any others in connection with the filter, for two reasons: First, the methods have not been economical, although much improved recently; secondly, the account is less accurate than others because of the difficulty which has arisen in special instances

in determining whether certain expenditures belong to this item or to others, like sanding or general maintenance work, and at times to hauling-accounts entirely foreign to the work of the filter. The account for 1897 is probably higher than it should be, but the writers can find no authority for changing from the amount given.

The rough contour of the ground north of the filter renders it necessary to use carts in hauling the dirty sand to the dump near the washer; whereas, if the area were more nearly level, cars upon a tramway could be operated by the laborers or by some smaller force than present conditions require. The extravagance of the current methods has been realized, and the trial of a machine-conveyer or some means of hydraulic transportation has been recommended, but the money for such installation has not been made available.

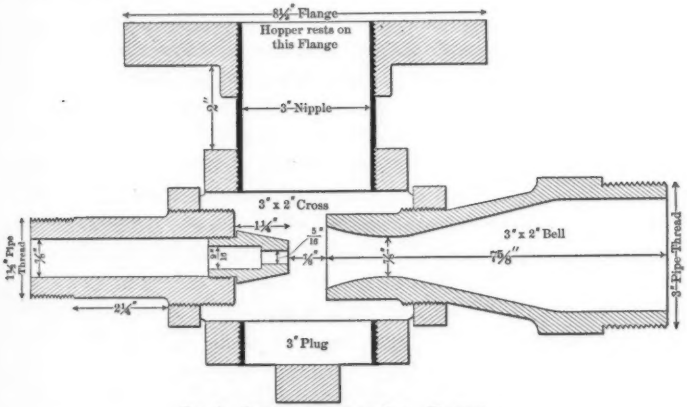


FIG. 3.—DETAIL OF JET OF SAND WASHER.

Detailed Study of Washing.—The washing machine used at Lawrence is, so far as the writers are aware, the only one of its kind in this country, and is similar to the design of some washers in service in Europe. The bowls of the machine are four in number and are light sweep-castings made at a local foundry. The sand drops to the bottom of each bowl or hopper and is caught by an inflowing horizontal jet and carried across and upward through a 3-in. pipe into the next bowl. The fitting at the bottom of the hopper is a standard 3-in. cross, with a plug in the bottom for the purpose of cleaning. Into a bushing in the inlet end of

the cross is placed a $1\frac{1}{2}$-in. pipe, to the end of which is attached a removable chilled-steel nozzle made from a piece of hexagonal rod. The nozzles in use have $\frac{5}{16}$-in jets, although other sizes have been tried. At the outlet of the cross there is screwed a special 3 x 2-in. reducer, the small end of which is placed within the cross and is of bell shape in order to readily receive the mingled water and sand. These special fittings, which wear out continually, are made as required at the shop of the Water Department. A sketch of the special nozzle, with all the attached fittings, is shown on Fig. 3.

The washer was built and erected early in 1895, and was first used on June 17th. The cost of the patterns, castings, piping, lumber, and labor on the machine was about $150, and that of the concrete pavements and drains about $240, while the labor account of the department for setting up, etc., was about $150, making a total cost of $540. Additional construction, new traveling hopper, draining boxes, etc., have been charged to the yearly maintenance accounts.

The presence in the sand of small stones, which would occasionally drop into the jet and stop the flow of the washer, rendered it necessary to screen all sand, both the old and dirty as well as the new, before throwing it into the first hopper. It was formerly the practice to screen the sand at the storage bank and wheel it to the washer, a process which required two men, and caused an irregular and intermittent feeding. During the summer of 1898, one of the writers experimented with different arrangements for transporting the sand, and, in a short time, devised the following method, which was adopted: A traveling hopper, mounted upon a light frame of piping and placed at will wherever dirty sand is dumped, is fed from a 2-in. pipe from the main supply. Sand thrown into the hopper is carried by the entering water into and through a connecting length of 3-in. pipe to the main washer, where it is raised about 5 ft. into the first hopper of the machine. The nozzle of the traveling hopper is $\frac{1}{2}$ in. in diameter. The 3-in. pipe line varies in length from time to time, and is made of running lengths of pipe connected in such lengths as are necessary for the distance. This method has been in use since July, 1898, and has never failed in carrying the sand to the washer from the most distant point required, about 200 ft. being the maximum tried up to the present time. It appears that the sand has not only been washed more thoroughly since using this apparatus, due probably to

a more complete mixing and scouring in the pipe line, but, also, there has been no apparent increase in the amount of water used, and, moreover, there has been a material reduction in the cost per yard.

From the last hopper, the cleansed sand is conveyed by water through a wooden trough to one of two draining boxes. Formerly, these boxes, each holding 3 cu. yds., were stationary, and after draining, the sand was shoveled into wheel-barrows and delivered along the dump for clean sand. In 1900 a further saving of time and labor was effected by the adoption of smaller boxes, or cars, on trucks, into which the sand is delivered from the washer, drained, and then carried on a narrow-gauge track to the storage bank where it is quickly dumped by removing one side of the car. The cost of these cars and track appears in the account for 1900. The washer, complete, with the old-style draining boxes, is shown in Fig. 1, Plate X.

Originally, the washing operations required 6 men, and more at times when the wheeling distance was considerable; now, 4 men do the entire work of screening, of attendance upon the machine, and of carrying away the clean sand to the dump. Thus, since the summer of 1898, the expense has been considerably less than before. Washing operations are generally begun each year about April 1st, and are suspended about December 1st. The ordinary water pressure at the machine, with everything running, is 63 lbs., and at the hopper 56 lbs. A statement of the cost of washing, the amount of sand washed, and the quantity of water used, with the unit factors for each, covering the last four years, and with less complete data for the years 1895 and 1896, is given in Table No. 16.

TABLE No. 16.—Details of Sand-Washing Operations at Lawrence Filter, for the Years 1895–1900.

Year.	Cost of Operations.			Cubic yards washed.	Cost per cubic yard.	Estimated number of cubic feet of water used.	Approx. Volume of water to sand
	Labor.	Bills.	Total.*				
1895	$990	$10	$1 000	1 500	$0.67	.....	.....
1896	2 110	10	2 120	.....	.....	.....	.....
1897	1 920	30	1 950	2 900	0.67	1 050 000	14
1898	1 540	60	1 600	2 600	0.62	970 000	14
1899	1 340	110	1 450	3 200	0.45	1 140 000	13
1900	1 290	220	1 510	3 000	0.50	820 000	10

* Cost of wash-water is not included.

The normal maximum amount of sand which can be washed in one day is 21 cu. yds., for which the item of labor of 4 men at $2 per day represents a cost of 38 cents per yard. The charges over and above this amount represent bills and labor for repairs and additional parts of the machine, necessary each year when the washer is made ready for service, and the cost of delays due to stopping the machine, shifting positions, and any other causes which tend to decrease the output below the maximum.

Detailed Study of Removal of Snow and Ice.—During the winter weather, that is, in the months of January, February and March, scraping can seldom be accomplished without the necessity of removing ice from the surface of the filter. Whenever the ice over that portion which is to be scraped is covered by snow, the latter is shoveled into carts and taken away. It was formerly the custom, also, to remove the ice in the same way after cutting; but, recently, this has been done at times only when teams are at hand, and more ice must be removed than the ice machine will handle. A layer of ice, about 15 ins. thick, in direct contact with the drained sand surface, is shown in Fig. 2, Plate X.

An ice-conveying machine was procured and set up during the winter of 1895-96, and since January 18th, 1896, has been in almost constant use during the winter season. The machine, quite compact and convenient, combines the power and the runway of the customary ice-house conveyer on a single framework; the whole being supported upon a car and truck moving upon a wide-gauge track. The boiler, engine and machinery is housed on the body of the car, while at one end is supported the framework of the elevator. This elevator is the usual style of long-link conveyer running over a power drum at the top and an idler at the bottom, and is supported upon a frame between guides. The runway of the conveyer can be placed at any slope, but when in use is at an angle of about 45° with the horizontal. The engine will develop 11 H.-P., and uses about 350 lbs. of coal per day when running. The conveyer travels at a rate of from 70 to 100 ft. per minute, and will hold 6 cakes of ice at once. The machine is capable of propelling itself along a track on the embankment, so that any part of the south side of the filter can be reached. The ice must be cut into cakes of a suitable size and fed to the conveyer, which then delivers it over the embankment upon a runway into the river, or

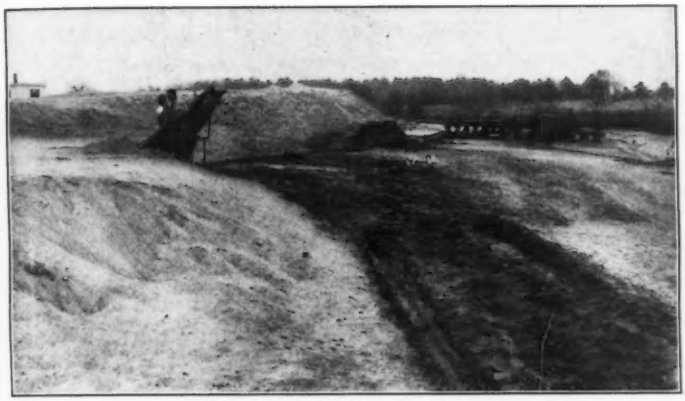


FIG. 1.—WASHING MACHINE AND TRAVELING HOPPER, LAWRENCE CITY FILTER.

FIG. 2.—THICK ICE ON SAND SURFACE AT TIME OF DRAINING LAWRENCE CITY FILTER.

on its frozen surface. If the ice is sufficiently thick, it is marked with a horse plow, and long cakes are then broken off and divided into small pieces capable of being caught by the carrier bars of the elevator. Inasmuch as a considerable amount of labor is required to cut the ice into small pieces, a saving might be effected with a more powerful engine, capable of moving a wider elevator at greater speed.

Ice has quite often appeared upon the filter surface by the middle of November, but becomes hardly thick enough to cut for several weeks, and generally disappears by the middle or last of March. The removal of ice over such beds as require cleaning is accomplished just before it is desired to scrape. If the cleaning of an adjoining area occurs shortly afterward, and the formation of ice does not prevent, it frequently happens that the ice already formed on the beds in question may be floated over the area scraped and its removal consequently avoided until some future date. The ice is rarely allowed to become thicker than 15 ins., and, generally, three or four crops are cut over portions of the surface.

The cost of removing snow and ice, in order to clean the filter in the winter time, is an expensive operation, and has varied from $1.90 to $2.90 per million gallons, according to the severity of the winter and the methods used. The average cost of removal has been $2.30 per million gallons filtered in a year, or about $1 100 per year per acre of net filter surface. The demands of consumption are such that the filter must be scraped as usual in the winter time, and the cost of ice removal is, therefore, greater than at other places where reserve filtering area is provided. Other than conveying, this item is probably the most expensive and wasteful of any part of the maintenance. The average yearly cost per acre, capitalized at 4%, is $27 500, a sum much in excess of the cost per acre necessary to erect a cover over the present filter, and greater, even, than the additional cost per acre of an approved form of covered masonry filter over a similar one not so covered.

The Efficiency of the Filter as Determined by Chemical and Bacteriological Analyses, and by the Decreased Prevalence of Typhoid Fever in the City of Lawrence.

General.—From the time of first operating the filter, the results of its work have been studied by the Massachusetts State Board of Health, which has conducted chemical and bacterial examinations of

the water of the Merrimac River as it flows upon the filter, and of the effluent of the filter at the pumping station, and after passing successively through the distributing reservoir, through the supply mains to City Hall, and, at length, at the extreme easterly end of the city to the Lawrence Experiment Station. It has been customary, especially during later years, to make daily bacterial analyses of the water at the several points just mentioned, during the months from November to April inclusive, and weekly examinations during the warmer season from May to October, when it has been found that the filter is more uniformly in a state of biological stability. The results of these studies have been published in detail in the Annual Reports of the State Board of Health, from which nearly all the data presented in the subsequent tables have been derived.

The water supply of Lawrence is for the most part pumped after filtration to an open distributing reservoir located upon a hill about ¾ mile from the river.* The reservoir consists of two basins of about equal size, having a combined capacity of 40 000 000 galls., equivalent to nearly two weeks' supply for the city. The inlet is arranged to partially aerate the water entering the reservoir by discharging into the air and allowing the water to fall upon a series of masonry steps over which it flows into both basins. From the reservoir the water travels through main distribution pipes for a distance of about 1½ miles to City Hall, and for a total distance of nearly 2½ miles to the Experiment Station.

Chemical Results.—During the construction of the filter, ground-water was encountered at various points in the excavation, particularly in the central and easterly portions. The superficial area of the southerly slope of the hill leading from the filter toward the reservoir, apparently tributary to the filter, is perhaps 23 acres, and the above-mentioned flow of ground-water probably represents the yield from this or a more extended water-shed. In this territory there are at the present time about a dozen dwelling-houses, many of which have by this time been connected with the sewer system, but some are yet provided with individual cesspools or privies.

The average yearly results of the weekly chemical examination of the water of the Merrimac River, and of the effluent from the filter

* Since 1896, about one-tenth of the water has been pumped independently to a closed stand-pipe just above the reservoir, to supply the people living upon the two main hills.

TABLE No. 17.—Results of Chemical Analyses of Applied Merrimac River Water and Effluent from Lawrence Filter for the Years 1893–1899 (Parts per 1 000 000).

Year.	Yearly rainfall, in inches.	Color.			Solids.						Chlorine.			Hardness.		
					Total.			Loss on ignition.								
		River.	Effluent.	Percentage removed.	River.	Effluent.	Percentage removed.	River.	Effluent.	Percentage removed.	River.	Effluent.	Percentage removed.	River.	Effluent.	Percentage removed.
1893, 3 months	....	0.39	0.33	15.4	44.3	....	.....	.....	....	.....	2.1	2.2	—4.8	...	...	.....
1894	31.35	0.42	0.34	19.0	37.0	61.0	—64.9	13.0	14.1	—8.5	2.1	2.5	—19.0	16	31	—94
1895	39 05	0.46	0.39	15.2	43.4	59.5	—37.1	17.5	17.0	2.9	2.4	2.8	—16.7	17	24	—41
1896	36.68	0.44	0.36	18.2	39.8	54.3	—36.4	15.2	16.4	—7.9	2.0	2.2	—10.0	13	19	—46
1897	41.77	0.45	0.42	6.7	38.4	51.7	—34.6	15.4	16.8	—9.1	2.1	2.3	—9.5	13	18	—38
1898	49.43	0 45	0.41	8.9	39.0	46.6	—19.5	16.3	16.9	—3.7	2.1	2.3	—9.5	12	17	—42
1899	34.87	0.36	0.33	8.3	39.9	44.4	—11.3	14.9	14.2	4.7	2.5	2.6	—4.0	12	16	—33
Average, six years	38.86	0.43	0.38	11.6	39.6	52.9	—33.6	15.4	15.9	—3.2	2.2	2.4	—9.1	14	21	—50

Year.	Dissolved oxygen in river, percentage of saturation.	Nitrogen as												Oxygen Consumed.		
		Free ammonia.			Albuminoid ammonia.			Nitrites.			Nitrates.					
		River.	Effluent.	Percentage removed.	River.	Effluent.	Percentage removed.	River.	Effluent.	Percentage removed.	River.	Effluent.	Percentage removed.	River.	Effluent.	Percentage removed.
1893, 3 months.	92	0.089	0.086	3.4	0.200	0.110	45.0	0.004	0.005	—25	0.14	0.37	—160	4.2	2.9	31
1894	81	0.083	0.083	0.0	0.194	0.095	51.0	0.001	0.001	0	0.12	0.39	—220	3.9	2.6	33
1895	.....	0.097	0.095	2.1	0.202	0.097	52.0	0.002	0.001	50	0.14	0.38	—170	4.4	3.0	32
1896	.....	0.094	0.084	10.6	0.198	0.096	51.5	0.001	0.000	100	0.14	0.36	—160	4.2	2.7	36
1897	.....	0.082	0.107	—30.5	0.203	0.098	51.7	0.001	0.000	100	0.14	0.43	—210	4.5	3.0	33
1898	.....	0.065	0.099	— 52.3	0.193	0.097	49.7	0.001	0.000	100	0.13	0.45	—250	4.4	2.9	34
1899	.....	0.113	0.083	26.5	8.203	0.083	59.1	0.003	0.001	68	0.15	0.36	—140	3.6	2.3	36
Average, six years	.....	0.089	0.092	—3.4	0.199	0.094	52.8	0.002	0.001	50	0.14	0.40	—190	4.2	2.8	33

Note.—The annual rainfall given in the table is the total annual precipitation at Lawrence, observed by the Essex Company on behalf of the United States Weather Bureau.

The "Solids" represent the average monthly determinations at the Boston Laboratory of the Massachusetts State Board of Health.

The determinations of color, solids and oxygen consumed on river samples were made after passing samples through filter paper. The color standards used were natural waters, the color of which had been accurately determined by comparison with Nesslerized ammonia standards, prepared as described on page 531, "Special Report on Examination of Water Supplies," and on page 329 of Annual Report of 1892, Massachusetts State Board of Health.

from its first operation to the end of the year 1899, are presented in Table No. 17.

Bacterial Results.—Table No. 18 shows, by months, the average numbers of bacteria in the water of the Merrimac River, as applied to the filter, and in the effluent of the filter at the pumping station and in the tap water at City Hall. During 1897, regular examination of samples collected at these points for *Bacillus Coli communis*, the representative bacterium indicating sewage contamination, was begun, and these studies have been continued to the present time. Where information regarding the occurrence of this organism has been available it has been included in the table.

The decreased efficiency of the filter during cold winter weather, especially in the first years of operation, has undoubtedly, in part, been due to the fact that the removal of ice is attended with such difficulty that only a portion of the filter can be scraped at any given time; while over the remainder of the area, when the filter is drained, the ice settles, becomes frozen to, and thus disturbs, the upper sand layers. On account of the many inherent difficulties attending the scraping of the filter in this weather, and because the cleaning of the beds nearest the pumping station was more effective in producing an increased flow, it oftentimes happened that only this portion of the filter was scraped. It is evident that the practice of scraping a part only of the surface at any given time, tends to produce high rates of filtration through those portions having a clean surface, and permits correspondingly lower rates through the area over which a more or less impervious *schmutzdecke* has already formed. Moreover, the drawing down of the water in the sand below the surface, the filter being uncovered, allows the upper layers of sand to become partially frozen, the effect of which is unquestionably disastrous to securing the highest bacterial efficiency.

Results of examination of samples of water from the outlet of the open distributing reservoir, although not included in the table, are, nevertheless, interesting because they show a considerable increase in the number of bacteria over the numbers in the effluent immediately after passing through the filter. It is probable, therefore, that the large increase in the numbers of bacteria found in the tap water at City Hall, principally during the warmer seasons of the year, as shown by the table, is either due to the organisms entering the open reservoir from

TABLE No. 18.—NUMBER OF BACTERIA IN THE WATER OF MERRIMAC RIVER, IN EFFLUENT OF FILTER AT PUMPING STATION, AND IN TAP WATER AT CITY HALL.

Month.	Number of days having complete series of samples.	Average Number of Bacteria per Cubic Centimeter.		Percentage of reduction in passing through filter.	Average number of bacteria per cubic centimeter in tap water at City Hall.	Further percentage of reduction in passing through reservoir and pipes.
		In water applied to filter.	In effluent of filter at pumping station.‡			
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1893.						
October†	24	21 000	560	97.3	130	77
November *..	15	7 700	190	97.5	71	64
December....	12	9 400	200	97.9	100	50
Average.....	.....	12 700	320	97.5	100	69
1894.						
January.....	23	7 600	140	98.2	56	60
February....	21	8 300	250	97.0	89	64
March.....	20	6 900	220	96.8	110	50
April.....	23	14 800	230	98.4	82	64
May.....	‡	6 000	130	97.8	130	0
June.....	‡	8 300	110	98.7	95	14
July.....	‡	2 400	25	99.0	92	—268
August.....	‡	3 100	36	98.8	140	—289
September ..	‡	6 500	42	99.4	85	—102
October	‡	25 300	120	99.5	81	32
November...	‡	16 600	180	98.9	72	60
December....	22	23 800	360	98.5	270	25
Average.....	.....	10 800	150	98.6	110	27
1895.						
January	27	18 700	210	98.9	140	33
February....	24	15 000	280	98.1	100	64
March	26	20 800	400	98.1	100	75
April.....	15	8 400	84	99.0	66	21
May.....	‡	7 000	68	99.0	170	—150
June	‡	9 000	68	99.2	64	6
July.....	‡	10 000	50	99.5	56	— 12
August.....	‡	5 000	38	99.2	55	— 45
September...	‡	5 000	40	99.2	50	— 25
October.....	‡	19 000	60	99.7	51	15
November...	17	8 700	64	99.3	50	22
December ...	24	6 700	84	98.7	60	29
Average.....	.....	11 100	120	98.9	80	33
1896.						
January.....	27	7 500	170	97.7	88	48
February....	22	12 600	320	97.5	170	47
March.....	17	6 100	140	97.7	98	30
April.....	25	3 800	40	98.9	57	— 42
May.....	‡	4 600	64	98.6	50	— 22
June.....	‡	10 000	58	99.4	71	— 22
July.....	‡	3 400	34	99.0	120	—247
August.....	‡	3 700	290§	92.2	120	60
September...	‡	13 800	35	99.8	100	—197
October.....	‡	9 900	31	99.7	44	— 42
November...	‡	5 800	50	99.1	39	24
December....	24	9 700	67	99.3	58	13
Average.....	.....	7 600	110	98.6	85	23

See notes on page 302.

TABLE No. 18—(*Continued*).

(1)	(2)	(3)	(4)	(5)	(6)	(7)
1897.						
January	22	13 300	91	99.3	49	46
February	23	13 100	79	99.4	48	39
March	26	12 300	67	99.5	62	8
April	25	6 900	47	99.3	51	— 8
May	†	4 500	35	99.2	73	—108
June	†	4 000	40	99.0	100	—150
July	†	6 300	110	98.3	300	—173
August	†	10 200	70	99.3	100	— 43
September	†	34 900	68	99.8	74	— 9
October	†	13 400	31	99.8	78	—152
November	25	6 600	27	99.6	43	— 59
December	26	5 600	24	99.6	26	— 8
Average		10 900	57	99.5	84	— 47

Month.	Number of days having complete series of samples.	Average Number of Bacteria per Cubic Centimeter. Total in river water applied to filter.	*B. Coli communis.*	Total in effluent of filter at pumping station.‖	Occurrence of *B. Coli communis* in effluent at pumping station.	Percentage reduction in passing through filter.	Total number of bacteria per cubic centimeter in tap water at City Hall.	Occurrence of *B. Coli communis* in tap water at City Hall.	Further percentage reduction in passing through reservoir and pipes.
1898.									
January	26	6 500	....	39	.....	99.4	34	.....	13
February	17	4 700	....	45	.....	99.0	28	.....	38
March	25	3 700	....	34	.....	99.1	62	.....	— 82
April	23	2 300	....	21	.....	99.1	30	.....	— 43
May	†	2 600	....	47	.....	97.6	19	.....	60
June	†	6 400	....	47	.....	99.3	39	.....	17
July	†	2 900	....	18	.....	99.4	53	.....	—194
August	†	3 800	....	32	.....	99.2	32	.....	0
September	†	3 700	....	68	.....	98.8	54	.....	21
October	†	4 200	....	26	.....	99.4	47	.....	— 81
November.	19	4 700	28	110	1(5 times)	97.7	150	1(4 times)	— 36
"	16	4 300	30	53	1(3 times)	98.8	140	1(3 times)	—164
December.	20	5 100	25	290	1(13 times)	94.3	260	1(11 times)	10
"	19	5 100	26	280	1(12 times)	94.5	260	1(11 times)	7
Average.	.....	4 400	....	65	.....	98.5	66	.....	— 2
1899.									
January	26	4 900	28	83	1(14 times)	98.3	90	1(5 times)	8
February	21	5 900	31	110	1(13 ")	98.2	69	1(5 ")	37
March	26	6 300	19	45	1(2 ")	99.3	42	1(3 ")	7
April	24	2 900	12	40	1(4 ")	98.6	33	0	18
May	14	1 900	21	17	0	99.1	17	0	0
June	†	4 500	55	100	0	97.8	47	0	53
July	†	3 000	63	14	1(once)	99.5	36	0	—157
August	†	5 100	21	20	0	99.6	47	0	—135
September	†	5 500	40	32	0	99.4	24	0	25
October	†	9 700	25	100	0	99.0	24	1(once)	76
November.	25	9 800	60	46	1(6 times)	99.5	38	0	17
December.	25	9 800	140	56	1(5 ")	99.4	37	0	34
Average	.....	5 800	43	55‡	.....	99.1	42	.....	24

* Excluding results of November 27th, when suction pipe was lowered in pump-well.

† Filter put in operation September 20th, 1893. The average results of 11 days after starting were: River, 37 000; Effluent, 6 200; Percentage reduction in filter, 83.2.

‡ Samples collected from rising main from pump. Examinations made weekly.

§ Increase due to test on pumps from August 10th to 22d, and emptying of force main on latter date.

‖ Excluding records for those days when the filter underdrains were being repaired; also for the two succeeding days.

the air, or to those developed in the water under the favorable circumstances. Notwithstanding this, however, it will be seen that throughout the greater portion of the year, a material decrease in the number of bacteria in the tap water is effected during its passage from the pumping station.

Relation of Scraping to Bacterial Efficiency.—Table No. 19 presents all the available data relative to the numbers of bacteria found in the effluent of the filter during periods of 3 days before and 3 days after the scraping of different numbers of beds, at times when daily analyses of the water were made. The table shows the efficiency of filtration at these times.

Of the 40 scrapings tabulated, 3 indicate no change in efficiency due to cleaning; on 21 occasions there was a decrease, and on 16 an apparent increase in the percentage removal of bacteria. It is significant, however, that of the 17 times when 12 or more beds were scraped (*i. e.*, about one-half or more of the entire filter surface) there were only 4 occasions on which an increased percentage of removal resulted, and 3 times when there was no apparent change, the remaining 10 times causing a decreased efficiency ranging from 0.1 to 2.9 per cent. During December, January and February, there were 13 times when less than 12 beds were scraped, and 4 times when more than one-half of the entire filter surface was cleaned. Of this later number, two indicated an increase and two a decrease in efficiency.

Inasmuch as daily bacterial examinations of the water of the river and of the effluent have not been carried on during the warmer months of the year, from May to October, when the filter is presumably in its most stable condition, the table probably represents the average and the worst effects only, produced by scraping.

Relation of Continuous and Intermittent Operation to Bacterial Efficiency.—Statements have already been made to show that the Lawrenc filter has been operated in the past, for varying intervals of time, bot intermittently and continuously. It has been possible to collect and present in Table No. 20 for purposes of comparison, data representing, from a bacteriological standpoint, the results of these two methods of operation. Twelve of the 16 periods of continuous operation occurred immediately after cleaning some part of the filter surface, while during 8 of the 9 periods of intermittent action, scraping was carried on. Under these circumstances, it is difficult to draw definite conclu-

TABLE No. 19.—AVERAGE NUMBERS OF BACTERIA IN EFFLUENT OF LAWRENCE CITY FILTER DURING PERIODS OF THREE DAYS BEFORE AND AFTER SCRAPING, AND PERCENTAGE RELATION TO AVERAGE NUMBER IN APPLIED RIVER WATER.

Date of scraping.	Number of beds scraped.	Designation of beds scraped, by numbers.	Average Number of Bacteria per Cubic Centimeter in Effluent during Three Days.		Average Percentage Removal from Applied River Water during Three Days.		
			Before scraping.	After scraping.	Before scraping.	After scraping.	Percentage decrease.
November 21 1895	2	Nos. 24-25.	75	120	99.3	99.0	0.3
February 22, 1896	2	Nos. 11-12.	400	280	96.9	97.8	—0.9
April 23-24, 1896	3	Nos. 1-3.	26	28	99.0	99.1	—0.1
October 21, 1893	4	Nos. 20-23.	170	110	97.9	96.9	1.0
March 15, 1898	4	Nos. 22-25.	37	37	99.5	99.2	0.3
January 31, 1896	4	Nos. 1-4.	46	84	98.9	98.3	0.6
March 10, 1898	5	Nos. 10-14.	73	28	97.0	99.5	—2.5
March 10, 1896	6	Nos. 16-21.	97	110	98.1	98.8	—0.7
April 7, 1897	6	Nos. 15-20.	44	42	99.2	99.6	—0.4
December 1-2, 1897	6	Nos. 10-15.	34	30	99.2	99.3	—0.1
January 5-7, 1898	6	Nos. 9-14.	120	23	98.5	99.7	—1.2
February 16-19, 1898	6	Nos. 8-13.	51	57	98.7	97.7	1.0
Average first group	4.5		98	79	98.4	98.8	—0.4
February 12, 1898	7	Nos. 1-7.	31	51	99.3	98.7	0.6
January 4-6, 1899	7	Nos. 15-17, 22-25.	100	130	98.1	97.9	0.2
November 15, 1899	7	Nos. 1, 2, 11, 12, 22-24.	30	20	99.5	99.8	—0.3
Dec. 31, 1896-Jan. 1, 1897	8	Nos. 3-10.	88	120	99.4	98.9	0.5
February 21-24, 1899	8	Nos. 15-22.	110	140	96.7	97.6	—0.9
December 10, 1896	9	Nos. 1-9.	40	27	99.3	98.8	0.5
November 17-18, 1897	9	Nos. 1-9.	16	20	99.8	99.7	0.1
November 27, 1897	9	Nos. 1-9.	19	34	99.7	99.2	0.5
February 26, 1898	9	Nos. 1-9.	84	16	98.0	99.5	—1.5
Average second group	8.1		58	62	99.1	98.9	0.2
January 5-6, 1897	11	Nos. 1, 11-20.	120	110	98.9	99.6	—0.7
January 11-15, 1898	11	Nos. 15-25.	23	11	99.7	99.9	—0.2
April 13-14, 1897	12	Nos. 1-7, 21-25.	33	46	99.6	99.2	0.4
April 28-29, 1897	14	Nos. 1 -14.	64	32	99.0	99.0	0.0
November 10-11, 1897	16	Nos. 10-25.	54	13	99.2	99.9	—0.7
November 22-23, 1897	16	Nos. 10-25.	20	19	99.7	99.7	0.0
April 20-22, 1897	18	Nos. 8-25.	46	50	99.3	98.0	1.3
Average third group	14.0		51	40	99.3	99.6	—0.3
November 26-30, 1895	23	Nos. 1-23.	95	48	99.0	99.0	0.0
March 22-26, 1898	23	Nos. 1-22, 25.	15	21	99.5	99.0	0.5
April 26-28, 1899	24½	Nos. 1-4, 6-25, ½.	18	41	99.3	98.7	0.6
December 27-31, 1895	25	Nos. 1-25.	120	75	99.0	98.8	0.2
April 8-10, 1896	25	Nos. 1-25.	54	39	98.2	98.8	—0.6
March 23-31, 1897	25	Nos. 1-25.	42	34	99.7	99.6	0.1
December 11-14, 1897	25	Nos. 1-25.	18	20	99.7	99.8	—0.1
April 27-28, 1898	25	Nos. 1-25.	27	28	99.4	98.7	0.7
April 5-6, 1899	25	Nos. 1-25.	12	96	99.2	96.3	2.9
November 21-24, 1899	25	Nos. 1-25.	36	210	99.5	97.9	1.6
December 5-8, 1899	25	Nos. 1-25.	150	26	98.0	99.7	—1.7
December 16-19, 1899	25	Nos. 1-25.	34	53	99.8	99.3	0.5
Average fourth group	24.6		52	58	99.2	99.0	0.2
General average	13.0		67	62	99.0	99.1	—0.1

sions, but as far as the data represent actual conditions, there seems to be no practical difference in the bacterial efficiency obtained with the two methods of operation.

TABLE No. 20.—Comparison of Numbers of Bacteria in Applied River Water and Effluent of Filter, during Periods of Continuous and Intermittent Operation.

Periods (Inclusive).	Number of Days.		Average Number of Bacteria per Cubic Centimeter in		Percentage of bacteria removed by filtration.
	In period.	When filter was drained.	Applied river water.	Effluent of filter.	
With Continuous Operation.					
Dec. 14-27, 1897	14	0	5 700	26	99.6
Jan. 15-24, 1898	10	"	7 600	25	99.7
Jan. 26-Feb. 9, 1898	15	"	5 100	36	99.3
Feb. 9-24, "	6	"	5 200	67	98.7
Feb. 26-Mch. 8, "	11	"	3 900	42	99.0
Mch. 15-20, "	6	"	4 600	30	99.4
Mch. 26-Apr. 7, "	13	"	1 900	22	98.8
Oct. 26-Nov. 8, "	14	"	3 400	14	99.6
Feb. 7-11, 1899	5	"	6 600	140	97.9
Feb. 13-19, "	7	"	5 100	88	98.3
Feb. 24-27, "	4	"	6 800	120	98.2
Mch. 14-18, "	5	"	5 300	42	99.2
Mch. 20-Apr. 2, "	14	"	4 800	34	99.3
Apr. 6-14, "	9	"	2 400	63	97.4
Apr. 28-May 2, "	5	"	2 800	49	98.2
Nov. 15-18, "	4	"	8 400	19	99.8
Average	9	0	5 000	51	99.0
With Intermittent Operation.					
Jan. 10-14, 1898	5	3	5 200	20	99.6
Dec. 1-5, "	5	5	8 300	88	98.9
Jan. 22-Feb. 2, 1899	12	7	5 200	84	98.4
Feb. 20-25, "	4	4	7 700	82	98.9
Mch. 3-6, "	4	3	9 300	71	99.2
May 7-10, "	4	3	700	18	97.4
Nov. 5-9, "	5	3	5 400	22	99.6
Dec. 3-7, "	5	4	10 200	96	99.1
Dec. 14-18, "	5	4	15 000	42	99.7
Average	6	4	7 400	58	99.2

Comparative Prevalence of Typhoid Fever in Lawrence Before and After the Introduction of a Filtered Water Supply.—For an extended period prior to the introduction of filtered water, the death rate from typhoid fever in Lawrence was excessive. During the ten years from 1859 to 1868, the local death rate from this disease averaged 8.34 per 10 000, placing the city in this regard fourth in the list of sixteen cities of Massachusetts which introduced public water supplies in the

years from 1869 to 1877.* In 1875, as already stated, there was introduced in Lawrence a public water supply, derived to some extent from the filter gallery, but for the most part directly from the Merrimac River, and used, after storage of about two weeks, in the distributing reservoir. From 1878 to 1889 the city's death rate from typhoid fever was 8.33 per 10 000, or the second in amount obtaining in the twenty-eight places in Massachusetts which were cities in 1891, the average rate of which was only 4.62 per 10 000.* During the last four years of this term the Lawrence death rate was 10.30 per 10 000, while the average for the other cities was practically the same as for the entire period.

An inquiry made by the State Board of Health into the cause of the excessive mortality from this disease in Lawrence developed the fact that from 1889 to 1893 the prevalence of typhoid fever followed with marked uniformity outbreaks of this disease in Lowell. The sewers of that city discharge directly into the Merrimac River 9 miles above the intake of the Lawrence Water-Works.

In order to show the benefit derived from the introduction of the filtered water supply in Lawrence, so far as it may be indicated by the decreased prevalence of typhoid fever, Table No. 21 has been prepared. This table gives the number of reported cases and deaths from this disease during the six years (1887–1892) prior to the year of construction of the filter, and during the six years (1894–1899) following its completion; together with the same data for the intermediate year, 1893, and the past year, 1900. The average death rate from this disease for the State has been added for purposes of comparison.

It will be seen that the average percentage of cases resulting in death during the first period was much greater than during the second. It is significant that a study by the State Board of Health of each case of the disease resulting in death, during the years from 1894 to 1896, and in 1898, showed that during the first year in question, 12 persons, representing 50% of the deaths from the disease in the city, were known to have used for drinking purposes the polluted canal water; in 1895, 9 persons, or 56%; in 1896, 2 persons, or 20%, and in 1898, 1 person

* Extended reference to the prevalence of typhoid fever in Lawrence as compared with other cities of Massachusetts, and the early decrease in death rate due to the introduction of filtered water, may be found in the papers by Mr. Hiram F. Mills, Chairman of the Committee on Water Supply and Sewerage of the Massachusetts State Board of Health, published in the Annual Reports of the Board, as follows: "Typhoid Fever in its Relation to Water Supplies," Annual Report, 1890, pp. 525–543; "The Filter of the Water Supply of the City of Lawrence and its Results," Annual Report, 1893, pp. 545–560.

only, of the total number dying from the disease was known to have used canal water for drinking.

TABLE No. 21.—Reported Cases of Typhoid Fever and the Deaths Resulting Therefrom in Lawrence, Before and After the Introduction of a Filtered Water Supply.

Year.	Number of Cases.		Number of Deaths.		Percentage of cases resulting in death.	Typhoid fever death rate for State of Massachusetts.
	Total reported.*	Per 10 000 population.†	Total.*	Per 10 000 population.†		
Six Years Prior to Construction.						
1887	134	33	47	11.7	35	4.5§
1888	208	50	48	11.6	23	4.5§
1889	217	51	55	12.8	25	4.1§
1890	193	43	60	13.4	31	3.7§
1891	207	45	55	11.9	27	3.6§
1892	172	36	50	10.6	29	3.5§
Average	188	43	53	12.0	28	4.0
Six Years Following Construction.						
1894	92	18	24	4.8	26	3.1§
1895	79	15	16	3.1	20	2.7§
1896	42	8	10	1.9	24	2.8§
1897	72	13	9	1.6	12	2.3§
1898	85	15	8	1.4	9	2.5‖
1899	135	22	20	3.3	15	2.3‖
Average	84	15	14	2.6	18	2.6
Percentage reduction	55	65	72	78	....	35.0
1893—year of consiruction	141	29	39‡	8.0	28	3.1§
1900	76	12	11	1.7	16	....

*Compiled from Lawrence and Massachusetts Board of Health Reports and other sources.

†Population for years intermediate between census enumerations have been interpolated.

‡Thirty three of this number occurred during the first eight months before the introduction of filtered water in September.

§Compiled from Massachusetts State Board of Health Report for 1898, p. 807.

‖Compiled from Massachusetts State Board of Health Report for 1899, p. 726.

In order to prevent the further use of the canal water, the drinking of which had long been customary among the operatives of the various factories, notices of warning were posted, after the introduction of the filtered water supply, at all places where this polluted water was available. It is believed, however, that a considerable length of time was required to bring about among the laboring people a clear understanding of the actual danger involved in drinking the unpurified water.

The average death rate from typhoid fever in the State of Massachusetts during the groups of years considered in the table, shows that the mortality from this cause has been decreased 35 per cent. The

apparent decrease for Lawrence alone was 78%; but deducting the possible effects, as indicated by the figure above, of improved sanitary conditions, including the general introduction of public water supplies, and of better methods of medical treatment, the actual benefit derived from the use of filtered water may perhaps be fairly represented by the prevention of the deaths of 40 persons out of every 100 dying from typhoid fever in Lawrence during the six years prior to the construction of the filter.

Acknowledgment.—In conclusion, the writers wish to extend thanks to their many friends who have aided in various ways to make this description and the data contained therein exact and truthful. They desire to express their obligations to Mr. A. D. Marble, City Engineer of Lawrence, for the preparation of a plan showing the location and layout of the filter and the territory in its immediate neighborhood. To Mr. R. A. Hale, M. Am. Soc. C. E., of the Essex Company, and to the officials of the various Municipal Departments, including the Board of Health, and in particular to the Water Board and its Superintendent, Mr. A. H. Salisbury,* the writers are indebted for much valuable information. Especial gratitude is due Mr. M. F. Collins, care-taker of the filter, who, through his great interest in this study, has willingly furnished all the data and statistics at his command.

Further than this the writers desire to express their acknowledgment to the Massachusetts State Board of Health, the results of whose careful and comprehensive studies have been published in their annual reports in such detail as to make the work of compilation satisfactory and not difficult. To the designer of the filter, Mr. Hiram F. Mills, Chairman of the Committee on Water Supply and Sewerage, of the Board, the writers wish to express their obligations for friendly advice and counsel.

† Died July 5th, 1901.

DISCUSSION.

ALLEN HAZEN, M. Am. Soc. C. E.—Perhaps no point in this paper is of more general interest than the statement in regard to the rapid increase in pollution of the river water. The authors refer to the amount of sewage entering the river during the years from 1887 to 1890 as about 1 gall. in 600 of the water passing Lawrence, which had increased, as they estimate, to 1 in 200 for the year 1900, or a threefold increase in eleven or twelve years. Mr. Hazen.

At first, this estimate of the increase would seem to be excessive, but a study of various matters connected therewith indicates that it is approximately right. Table No. 22 shows the total population upon the water-shed, computed from each national census from 1850 to 1900, and also that part of the whole living in cities and towns.

TABLE No. 22.—POPULATION ON THE WATER-SHED OF THE MERRIMAC RIVER ABOVE LAWRENCE.

Year.	Total population upon water-shed.	Urban: Cities and towns over 4 000.	Rural: Towns under 4 000.	Cities and towns having sewers.	Cities and towns having purification works.	Computed relative amount of pollution.
1850	252 000	75 000	177 000	.....	.....	16 000
1860	282 000	101 000	181 000	.....	.....	19 000
1870	306 000	124 000	182 000	.....	.....	21 000
1880	351 000	176 000	175 000	138 000	.....	63 000
1890	416 000	255 000	161 000	207 000	9 000	140 000
1900	482 000	318 000	164 000	312 000	59 000	250 000

Table No. 22 also shows the population in towns having sewers at the various dates, as nearly as the speaker can obtain the figures, and the population of towns having sewage purification works. These results are shown graphically in Fig. 4.

For the purpose of estimating the relative pollution of the river at the various periods, the speaker has attempted to reduce the sewage pollution from the various classes of population to an equivalent pollution from population connected with sewers discharging directly to the river. In doing this it is necessary to make a number of estimates which, from the nature of the case, can only be roughly approximate. The first estimate is of the proportion of the population connected with the sewers in towns having sewers. Most of the larger cities upon this water-shed introduced water and constructed sewers in the decade ending with 1880. The proportion of the population connected with sewers in 1880 was comparatively small. Generally, the sewers at first reached only the more densely populated areas. Cesspools were in common use, and as some trouble and expense were

Mr. Hazen. involved in making sewer connections, the use of cesspools was only slowly discontinued. The proportion of the population connected with sewers in sewered towns has steadily increased until at the present time most of it is so connected.

For the purpose of this estimate it is assumed that 30% of the population in cities and towns having sewers was connected with the sewers in 1880; 60% in 1890, and 90% in 1900. The remainder of the population is assumed to have the same polluting effect as if living in unsewered towns. It is further assumed that the sewage effluents in towns having sewage purification works, including the chance of discharge of raw sewage, have 20% of the polluting power of the raw sewage, and that the pollution from the population in unsewered towns of 4 000 inhabitants and over is equivalent to the sewage of one-tenth, and that from rural population to one-twentieth, of that population, discharged directly. The relative pollution of the river at different times, computed in this way, is shown by the last column in Table No. 22.

These results indicate that, in a general way, during the last three decades the pollution of the river has doubled every ten years, or, in other words, the annual increase in pollution has been about 7%, a figure only a little less than that indicated by the authors' statement. This result is confirmed by analyses of the river water made by the State Board of Health. The annual average free ammonia of the river water above Lawrence is probably, on the whole, the best index, from a chemical standpoint, of the amount of sewage pollution. The figures have been as shown in Table No. 23.

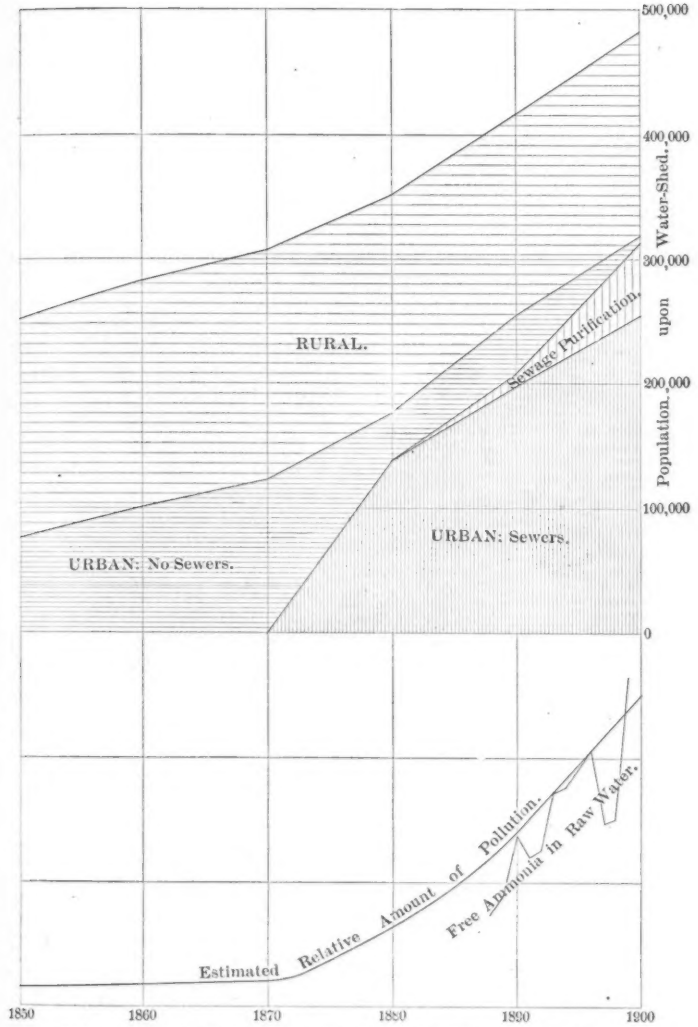
TABLE No. 23.

Year.	Annual average free ammonia in raw water at Lawrence, in parts per 100 000.	Year.	Annual average free ammonia in raw water at Lawrence, in parts per 100 000.	Year.	Annual average free ammonia in raw water at Lawrence, in parts per 100 000.
1888....	0.0026	1892....	0.0042	1896....	0.0068
1889....	0.0030	1893....	0.0057	1897....	0.0049
1890....	0.0046	1894....	0.0062	1898....	0.0050
1891....	0.0040	1895....	0.0064	1899....	0.0088

There is some fluctuation from year to year, but, on the whole, the increase corresponds substantially to the rate just indicated. This is shown by Fig. 4, in which the free ammonia is plotted in comparison with the relative pollution as just computed.

It should be said, in justice to those who were responsible for the introduction of the raw water a quarter of a century ago, that the river water was, at that time, from the present standpoint, comparatively unpolluted; and it is not improbable, that, looking at the

Mr. Hazen.



POPULATION UPON THE WATER-SHED OF THE MERRIMAC RIVER, ABOVE LAWRENCE; AND INCREASE IN AMOUNT OF POLLUTION.

FIG. 4.

Mr. Hazen. matter broadly, the introduction of a public water supply in its time was as great a step in advance as the construction of the filter at a later date.

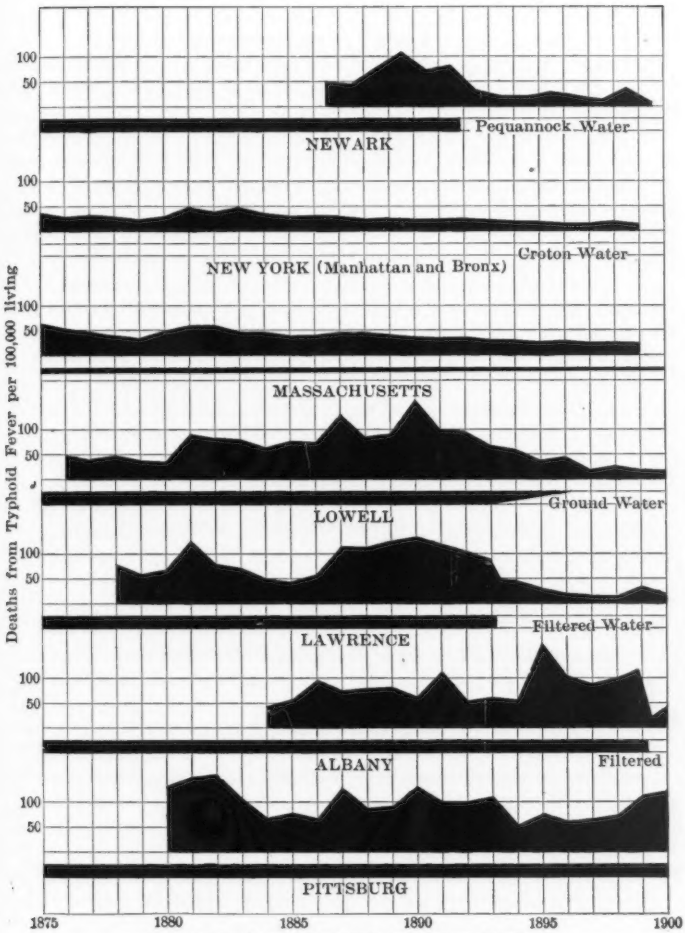
The comparison between different water-sheds, made by the authors, is interesting, but their figures need some revision. Their estimates of the growth of rural population are too great. Rural population in the Northeastern States has rarely increased in the last thirty years, and has often decreased. On the water-shed of the Hudson, above Albany, the total population, by the census of 1900, is only 80 per square mile instead of 93, as estimated by the authors.

TABLE No. 24.—DRAINAGE AREAS, AND URBAN POPULATIONS UPON THEM, OF CERTAIN RIVERS USED FOR WATER SUPPLIES.

Place.	River.	Drainage area, square miles.	Urban population upon drainage area above intake, 1900.	Population per square mile.
Chester, Pa.	Delaware	10 450	1 810 029	173
Philadelphia, Pa.	Schuylkill	1 915	186 682	98
Lawrence, Mass.	Merrimac	4 634	317 869	69
Albany, N. Y.	Hudson	8 240	376 001	46
Poughkeepsie, N. Y.	Hudson	11 600	531 687	46
Schenectady, N. Y.	Mohawk	3 400	142 208	42
Wilkesbarre, Pa.	Susquehanna	9 850	315 371	32
Philadelphia, Pa.	Delaware	8 186	242 788	30
Louisville, Ky.	Ohio	91 000	2 303 305	25
Evansville, Ky.	Ohio	107 000	2 560 853	24
Harrisburg, Pa.	Susquehanna	24 030	584 672	24
Paterson, N. J.	Passaic	773	17 205	22
Cincinnati, Ohio.	Ohio	72 400	1 572 527	22
Pittsburg, Pa.	Monongahela	7 600	156 412	21
Trenton, N. J.	Delaware	6 916	145 707	21
Troy, N. Y.	Hudson	4 570	85 864	19
Toledo, Ohio.	Maumee	6 723	112 470	17
Pittsburg, Pa.	Allegheny	11 400	182 332	16
Elmira, N. Y.	Chemung	2 107	27 973	13
Grand Rapids, Mich.	Grand	4 800	46 874	10
Quincy, Ill.	Mississippi	135 000	1 146 173	8
Davenport, Ia.	Mississippi	87 842	670 274	8
Washington, D. C.	Potomac	11 476	79 563	7
Dubuque, Ia.	Mississippi	81 322	588 884	7
New Orleans, La.	Mississippi	1 261 084	9 162 139	7
St. Louis, Mo.	Mississippi	700 663	4 393 016	6
Binghamton, N. Y.	N. Br. Susq.	2 279	14 780	6
Chattanooga, Tenn.	Tennessee	21 418	61 826	3
Knoxville, Tenn.	Tennessee	9 530	29 189	3
Richmond, Va.	James	6 800	18 891	3
Kansas City, Mo.	Missouri	426 893	653 667	2
Little Rock, Ark.	Arkansas	157 466	285 507	2
St. Joseph, Mo.	Missouri	426 000	501 902	1
Minneapolis, Minn.	Mississippi	19 585	21 961	1
Omaha, Neb.	Missouri	322 500	87 554	0.3

Table No. 24 shows the drainage area of rivers at points where they are used for public water supplies by some of the larger cities in the United States, and the urban populations upon these water-sheds, including all cities and towns of more than 4 000 inhabitants, by the census of 1900.

Mr. Hazen.



TYPHOID FEVER DEATH RATES AND WATER SUPPLIES.

Fig. 5.

Mr. Hazen. The urban population upon a water-shed is one of the most useful indications of the relative pollution of the water; but it must be remembered that there are many other considerations, such as velocity of flow, and amount of precipitation and evaporation, which must be taken into account; and if this could be accurately done, the order of the cities in this table might be very greatly changed. Rural population on a water-shed is a much less important source of pollution than urban population.

The cost of operation of the Lawrence filter seems excessive, when compared with figures for plants built in sections and more conveniently arranged for economical operation. It should not be forgotten, however, that this was accompanied by very low cost of construction; and when reasonable interest and sinking fund charges are taken into account, the total cost is quite moderate. The absence of preliminary pumping is an important element in this result. The results at Lawrence and at Albany may be compared, for instance, with an allowance of 5% for interest and sinking fund charges, and, using round figures, are shown in Table No. 25.

TABLE No. 25.

	Lawrence.	Albany.
Cost of plant	$70 000	$500 000
Quantity of water per annum, million gallons	1 210	4 400
Cost of operation per million gallons	$7.70	$4.75
Cost of operation per annum	$9 350	$20 900
Interest and sinking fund charges, 5%	3 500	25 000
Total cost per annum	12 850	45 900
Cost per million gallons	10.64	10.43

These figures indicate that the total cost of filtered water delivered in the pump-well, including all preliminary expenses, is substantially the same at Lawrence and at Albany.

The most striking result of the Lawrence filter has been the reduction in the city's typhoid fever death rate. In Fig. 5 this death rate is plotted from 1878 to 1900. For comparison, corresponding death rates for Newark, New York City (Manhattan and Bronx), State of Massachusetts, Lowell, Albany and Pittsburg are shown for as many years as data are available.

Under each death-rate plotting there is a band indicating the character of the water supply. Unpurified river water is indicated by a black band. Unpolluted or purified water by a light band. Under Massachusetts, the proportion of black in the band shows approximately the proportion of the total population in towns not having public water supplies, as Dr. S. W. Abbott, Secretary of the State Board of Health, has shown that in the whole State the amount of

typhoid fever has decreased in substantially the same ratio as this part of the population. Mr. Hazen.

The conditions in Lowell have been, in many respects, similar to those in Lawrence. Lowell is eight miles above Lawrence on the Merrimac River. Both cities used the Merrimac River water, while the other cities on the river did not. When the river water was first introduced the typhoid fever death rates decreased, indicating probably that the river water was, at that time, on an average, less poisonous than the wells which it superseded. Afterward, with the rapidly increasing pollution, the typhoid fever rates increased in both Lowell and Lawrence, until about 1890, when they became so high as to attract serious attention; with the result that the conclusion was reached that the river water was responsible for a large number of the deaths from typhoid fever; and measures were taken for improving or changing the supplies.

In Lawrence the city filter was constructed. In Lowell an underground source of supply was secured. At Lawrence the change was made in September, 1893, while at Lowell it extended over three years, from 1893 to 1896, as shown by Fig. 5. The reductions in the death rates in both cities were very marked. In Lawrence the reduction was more abrupt than in Lowell, corresponding to the way in which the supply was changed. Both cities now have substantially the same typhoid fever death rates, which rates are slightly lower than the average for the State.

In both cases the reduction in the typhoid rate seems to have commenced a little before the change in the water supply. The same thing has also been observed in other cases, and has been taken by many as an indication that the change in the supply was only responsible for a part of the reduction, and that much of the improvement would have been realized even though no change had been made in the water supply.

In the cases of Lowell and Lawrence, at least, the speaker thinks there is nothing to bear out such an assumption. Prior to 1890 the typhoid fever rates in both cities had increased rapidly, notwithstanding the improvements in the methods of treating the disease, and in the general sanitary conditions, to which the authors refer. The pollution of the river water was increasing rapidly, and, had no change been made in the water supplies, there is every reason to believe that, notwithstanding the continued improvements in the directions mentioned, the typhoid fever death rates would have increased, and would have been greater at the present time than ten years ago.

How, then, shall we account for the reduction just before the introduction of the new water? There may be various reasons, but two circumstances at least deserve consideration. In the first place, the typhoid fever death rate fluctuates from year to year. The conditions

Mr. Hazen. which control the dissemination of the disease by water are complicated and change with conditions of weather, stream flow, etc. Generally, the highest rates occur at intervals of several years, between which lower rates are observed. An unusual increase in typhoid fever attracts attention, excites public interest, and results in the determination to get a new source of water supply. The new supply is generally introduced a few years later, when, in the natural course of events, there has been a decline in the typhoid fever death rate from the summit, and before the inevitable increase to another summit has begun. A second reason for the decline prior to the introduction of the new water is that the official recognition of the injurious character of the water, which is involved in the determination to secure another source of supply, makes the inhabitants more careful in the use of the existing supply, and in this way tends to reduce its effect upon the death rate.

The reductions at Lawrence and Lowell for the years 1890 to 1892 were hardly more striking than corresponding reductions at Albany and Pittsburg, shown in Fig 5; but there is this difference, that at Lawrence and Lowell, with a new water supply, the reduction continued at an accelerated rate, while at Albany and Pittsburg the reduction did not continue, but on the contrary, rates have since occurred as high or higher than those previously experienced. In speaking of Albany, reference is made only to the period prior to the introduction of filtered water. Since that time, the death rate has been much lower.

An interesting comparison is furnished by Newark, which introduced in 1892 a gravity supply from unpolluted sources in place of the Passaic River water previously used. The reduction in the typhoid death rate at Newark was almost as striking as at Lawrence and Lowell.

In view of the foregoing, the speaker believes that the authors' estimate of the amount of reduction due to the construction of the filter is far below the truth; and that in case the water supplies of Lowell and Lawrence had remained as they were in 1890, the death rates would have increased instead of decreasing as they have done. The introduction of a new water supply in each case resulted in a radical reduction in the typhoid fever death rate, and the reduction at Lawrence, where filtered water from a very highly polluted source was used, was quite as great, and the subsequent death rate has been as low, as at Lowell, where the new supply was a ground-water, which can hardly be supposed to carry any germs of disease, and as at Newark, where the new supply is from unpolluted sources.

While the most striking reduction in the death rate following the use of filtered water was in typhoid fever, the general death rate showed a very considerable reduction. Table No. 26 shows the death

rate per thousand living for the seven years that the filter has been in operation, together with the corresponding rates for three preceding periods of seven years each. Mr. Hazen.

TABLE No. 26.—DEATH RATES IN LAWRENCE BY SEVEN-YEAR PERIODS, 1873 TO 1900.

Year.	Total deaths per 1000.	Year.	Total deaths per 1000.	Year.	Total deaths per 1000.	Year.	Total deaths per 1000.
1873.....	20.6	1880.....	21.7	1887.....	22.5	1894.....	19.0
1874.....	21.7	1881.....	20.4	1888.....	19.1	1895.....	20.3
1875.....	26.0	1882.....	22.3	1889.....	25.7	1896.....	20.3
1876.....	22.3	1883.....	21.8	1890.....	26.6	1897.....	20.6
1877.....	22.7	1884.....	22.9	1891.....	24.5	1898.....	19.7
1878.....	22.2	1885.....	19.9	1892.....	26.2	1899.....	20.5
1879.....	20.8	1886.....	20.0	1893.....	24.2	1900.....	20.0
Average..	22.3	.....	21.3	.....	24.1	.....	20.1

The reduction in the general death rate in the last seven years, as compared with the seven preceding years, is several times as large as the reduction in the typhoid fever death rate, and perhaps indicates the effect of the quality of the water on other diseases. The question as to how far this is due to the water supply, and how far to improved general sanitary conditions, may be properly raised; but the very decided reduction at the time of the introduction of the filter. and the steadiness with which the rate has continued on a lower level since, seem to indicate that the water supply had something to do with the reduction, and that the coincidence was not accidental.

There is a particularly interesting history connected with this filter, which, unfortunately, is not included in the paper. This history relates to repairs made to the underdrainage system in 1898. These repairs were made necessary because there was no water-tight bottom to the filter, and a certain amount of ground-water entered from below, and this ground-water carried iron, and where the iron-containing ground-water came in contact with air, or aerated water, conditions were formed which allowed the growth of a plant called *Crenothrix*. The growth of *Crenothrix* took place about and in the underdrains, and gradually closed them. It became evident that unless something was done, a sufficient supply of water could not be secured. To correct this it became necessary to dig up and reconstruct the drainage system. As the filter is all in one unit, the work had to be done during the short intervals when the filter was drained; and it is perhaps not surprising that, owing to the disturbance, the bacterial efficiency fell considerably, namely to 97.7% for November, and to 94.3% for December, 1898, after which the efficiency rapidly regained its ordinary standard. This decreased efficiency was followed early in 1899 by a very con-

Mr. Hazen. siderable increase in the number of cases of typhoid fever in the city, and the deaths from this cause for the year were about double, or ten more than the average for the years before and after.

On the face of it, and in the absence of other explanation, it seems probable that this increase in the typhoid fever death rate was the price which the City of Lawrence paid for repairing the filter while maintaining the supply from it; and the speaker thinks that this experience may teach one of the most useful lessons to be found in the history of the Lawrence filter. It shows, as a number of corresponding experiences in Europe showed many years ago, that a very slight falling off in the efficiency of filtration may affect to a considerable extent the health of the people using the water; and that the death rate of the city is decidedly a function of the number of bacteria remaining in the filtered water, even though that number is comparatively small.

The question may be raised as to whether even the best possible filtration removes all the typhoid germs from the water, and whether some of the remaining typhoid fever in the city is not caused by the filtered water, even under the most perfect conditions. Present evidence is certainly not conclusive on this point. The most that can be said is that such a reduction in the number of bacteria as is caused by the best filtration reduces very largely the death rate from typhoid fever among the users of the water; and that water so filtered, even though taken from much-polluted sources, compares favorably from a hygienic standpoint with the best water supplies otherwise obtained. No certain evidence can be produced that typhoid fever is caused by waters filtered by what may be considered the best methods, nor, from the nature of the case, can evidence be produced that no typhoid fever is caused by them; but it is known that if any is caused, the amount must be extremely small.

This experience at Lawrence should warn us that it is not safe to regard as unimportant the numbers of bacteria passing a filter, and to regard one percentage of removal as good as another as long as all the percentages are above some arbitrary limit; and in the present state of the art the speaker thinks that we should not be content with anything less than the highest bacterial efficiency which can be obtained by any practicable means.

The authors' statement that the filter was constructed according to plans and directions given by the State Board of Health is, the speaker believes, not strictly correct. The plans were not furnished by the Board, but by Mr. Hiram F. Mills, a member of the Board, who acted in this connection entirely as a public-spirited citizen, and not officially. Mr. Mills gave his services to the city and received no compensation for them.

Mr. Mills' personal interest in the filter should not go without

notice. He was Chief Engineer of the Essex Company. The Essex Company had created Lawrence, and was, perhaps, more directly interested in its welfare than any other corporation or individual. It is hardly possible to speak too highly of Mr. Mills' interest in the city, and in securing for it that which was best. The speaker does not overstate the case in saying that the construction of the Lawrence filter was solely due to the untiring and well-directed efforts of Mr. Mills, who met and overcame all the objections which were raised to it, and carried the project through successfully. Mr. Hazen.

The Lawrence filter has resulted in saving many hundred lives and preventing thousands of cases of sickness. Its original purpose has been splendidly achieved, and all the expenditures involved would have been fully justified even though they had been many times greater than they have been. The lessons that can be learned from its history are many; but, perhaps, none is more important than the courageous application of principles deduced from careful experiment and well-founded theory, but not yet substantiated by practice.

The Lawrence filter was in a large sense the beginning of water purification in America. This is particularly true when the matter is considered from a hygienic standpoint. A few filter plants had been built in America before the Lawrence filter, but these earlier plants had been directed largely or principally toward improving the physical character of the water. At Lawrence, for the first time, a filter was constructed with the deliberate purpose of reducing the death rate. The success that was achieved in accomplishing this result attracted the attention of the whole country, and was of the greatest service in directing attention and energy to a most important subject, which up to that time had not received the attention which it deserved.

Robert Spurr Weston,* Esq. (by letter).—The authors have certainly done much to advance the knowledge of the subject of water purification by this complete compilation of data connected with the Lawrence filter, the classic of its type, in America. Mr. Weston.

The educational value of this paper must be very high, as the authors have faithfully recorded the various steps which have been taken since the inception of the work and in the direction of better and more economical operation.

The paper has a value in helping us to realize how much sanitary science owes to Mr. Hiram F. Mills and his associates who gave freely of their time and knowledge, in spite of local distrust, and, on a small appropriation, built a filter which has stood so well the test of over seven years of daily operation.

The authors have treated their subject so carefully and so judicially that there is little to be said in criticism.

* Resident Expert, Water Purification Station, New Orleans, La.

Mr. Weston. They have brought out, among others, the following important points:

a. The efficiency of the filter, as made evident by the improved health of the community.

b. The permanency of the results obtained.

c. The trouble due to entrainment of air, caused by filling the filter rapidly from above.

d. The efficiency of continuous, as compared with intermittent, filtration.

e. The lack of economy shown in not building covered filters and in not equipping the plant better generally.

f. The economies effected in the cost of scraping, sand washing, etc.

They have also succeeded in bringing to light many useful and hitherto inaccessible data as to cost.

The writer would like to ask whether or not there were any difficulties experienced on account of the character of the bottom of the filter, which, he has always understood, was not made absolutely water-tight?

The average total hardness of the Potomac water, as determined by the writer, is 93 parts per million; this figure might fill the blank in Table No. 3.

Mr. Bailey. GEORGE I. BAILEY, M. Am. Soc. C. E.—Students of water purification have long been in debt to the Lawrence, Mass., water filter, for the work it has done, and to the Massachusetts State Board of Health for making known the results obtained. This debt is now further increased by the very comprehensive and complete descriptions and details of operation and cost given by the authors of this paper.

This plant does not now represent the best practice, either in design or in operation, and the lessons of what to avoid are indicated by the details of cost given. A few of these points seem to be:

1.—The desirability of subdividing the filter area into two or more units, of such size that one unit may be taken out of use for cleaning or refilling with sand, without embarrassing the general operation or the water supply.

2.—The desirability of covering filters, where the winter temperature approaches that at Lawrence.

3.—The substitution of other than manual labor, where it is possible and feasible, to carry out the maintenance operations.

To make comparisons along these lines, in addition to the data given in this paper, there are available the records of the Poughkeepsie filter,* the operation expense for the Mount Vernon filter,† and also the operating cost of the Albany filters.

* Fifth Annual Report of the Board of Public Works, Poughkeepsie, N. Y., for the year 1900.

† *Engineering News*, May 30th, 1901.

Mr. Bailey.

In Table No. 27 these records are compared with those of the Lawrence filter for the year 1900, except that the Albany records are for the sixteen months' operation from September, 1899, to December 29th, 1900.

Table No. 27 is arranged as near as may be by corresponding items.

TABLE No. 27.—Cost per Million Gallons Filtered.

Lawrence.		Poughkeepsie.		Mount Vernon.		Albany.	
Scraping	$1.75	Cleaning beds	$1.31	Cleaning	$1.31	Scraping and Wheeling out	$0.69
Sanding	1.02	Washing and replacing sand	0.82	Overhaul	1.43	Refilling	0.32
Washing	1.25			Washing	0.75	Washing	0.42
General	0.60	Labor, care of grounds, tools, etc	1.59	Miscellaneous	0.10	Incidentals and lost time	0.23
Removing ice	1.92		0.60		0.23		
Conveying	1.16			New sand	0.23		
Totals	$7.70		$4.32		$4.05		$1.66

The filters at the first three places are uncovered, at Albany they are covered.

The number of units in the plants are, at Lawrence 1, at Poughkeepsie 3, at Mount Vernon 3, at Albany 8.

Direct comparisons of these costs cannot be made, as each city has some item not included in the others, and the cost is upon a different basis, as follows:

At Lawrence, laborers are paid $2.00 for nine hours' work. At Albany and Poughkeepsie, the pay is $1.50 for eight hours' work. Lawrence, therefore, pays 18.5% more for labor. It is not exactly correct to reduce Lawrence's gross cost by this amount, but, as nearly all the operating cost is for labor, in so reducing it a comparative basis is more nearly obtained. The item "Conveying" is for work not necessary to the same extent at the other plants, and is probably due to the location of this individual plant and not to filtration generally.

At Poughkeepsie 1 000 cu. yds. of sand were scraped from the beds. Only 910 cu. yds. were washed and replaced. To round out the cost, an additional amount of $0.07 should be added. The quantity of water used in washing sand by their method is estimated to be 18 to 1. The cost of this water is not included, and, on the basis of their pumping expenses, $0.10 should be added for this.

In Mount Vernon no cost is added for wash water. Their washer is approximately the same as at Lawrence and Albany. This allowance should therefore be about $0.05. In their cost no charge is made for maintenance of grounds, that being charged to "Pumping Station." Without any definite information, it is assumed that this cost is approximately $0.20 per million gallons. In their exhibit there is an

Mr. Bailey. item of $0.23 for new sand, which should be omitted, as it should be charged to construction, or, if it is to make up for sand lost in washing, it should be distributed through all the years of operation.

TABLE No. 28.—ADJUSTED COMPARISONS OF COST PER MILLION GALLONS FILTERED.

	LAWRENCE.	POUGHKEEPSIE.	MOUNT VERNON.	ALBANY.
Scraping	$1.43	$1.31	$1.31	$0.69
Sanding	0.84	0.98	1.41	0.32
Washing	1.02		0.37	0.42
Removing ice	1.57	0.60	0.23	0.61
General	0.49	1.59	0.30	0.23
Conveying	0.95	.....	.....	.....
Total	$6.30	$4.48	$3.62	$2.27

At Albany, the filters are covered. If this were done only to prevent ice formation and ice removal, to compare with other plants, the cost of the covering, say, $15 000 per acre, at 3½% for sixteen months, and this were divided by the quantity filtered, the charge for ice removal would be $0.61.

By recalculating a few other items, to reduce them to a common basis, and taking into account all of the foregoing, the ordinary cost of filtering by this method would be as shown in Table No. 28.

The basis of all operation of sand filters is the work done with the filtering sand. Its handling, its scraping, its moving out, washing and replacing in the bed, and the conveniences and facilities for handling the sand, or the lack of them, make up the cost. It is interesting to note that the cost of each of these plants is almost directly proportional to the amount of sand handled, as is shown in Table No. 29.

TABLE No. 29.

	Millions of gallons filtered.	Sand handled. Total cubic yards.	Sand, in cubic yards per million gallons filtered.	Proportional percentage.	Cost. Percentage of sand.	Cost. Actual.
Lawrence	1210.	3 000	2.48	39.4	$6.30	$6.38
Poughkeepsie	653.3	1 000	1.53	24.3	4.48	3.94
Mount Vernon	679.4	955*	1.41	22.4	3.65	3.63
Albany	6463.	5 673	0.88	14.	2.27	2.27
Totals	.....	.....	6.30	100.	....	....

* New sand deducted.

The water at Albany is more turbid, and contains more suspended matter than at either Lawrence or Poughkeepsie, and it is presumed

more than at Mount Vernon. Ordinarily, this would involve a greater cost of operation at Albany than at any of the other cities. Generally speaking, the turbidity and suspended matter in the water are the dominant factors which control the selection of a method of filtration, and the numerous investigations that have occurred, and are now being had, pay chiefest attention to these items. If all waters were reasonably free from these properties, there would be little discussion as to the method of filtration to be used, except possibly for the removal of color. Mr. Bailey.

At Lawrence, Poughkeepsie and Albany the work is carried on by a municipal corporation, with all the political influences which tend to add to the cost of work. At Mount Vernon it would be expected that, as the filter is controlled by a private company, the work should be more economically done, and, to some extent, the figures bear this out.

Taking into account these different factors, it is seen that the costs at Lawrence, Poughkeepsie and Mount Vernon are greater than at Albany, although it might be expected that the cost at Albany would be the greatest. Each of the items of handling sand is less at Albany than at the others, and, in the speaker's opinion, this is a clear indication that the effect of the covers is felt throughout and upon all operations. The cost is greatest at the plant of a single unit.

A decided benefit in covering filters is the maintenance of the laborer's organization. These men are paid only when they work, and they want fairly steady work or they will seek other employment. It pays the management to retain experienced men, for, as they become broken in to the work, they will do nearly double the amount done by inexperienced men. With covers on the filters, the men scrape a filter during any storm; therefore, a rainy day means no loss of wages. They remove the scraped material, for the long run of the barrow, and its filling, is done under cover, and they do not object to a slight wetting. In winter they are shielded from winds and storms; the temperature inside the filter is less than outside, and the men make full time, irrespective of weather, and without any special discomfort.

These benefits of covers are entirely without consideration of any climatic or thermal conditions regarding the efficiency of filters. Such benefits have been so often mentioned, that it is useless to mention them here.

There is one cost of filtering, at a plant having only one unit, or which is badly subdivided, which does not show in the filter records, but appears only in the pumping cost. Where the entire filter area is of a size to yield daily only the quantity of water needed, and it is all in one unit, the cost of pumping is increased at every cleaning, as the pumps are necessarily shut down and the fires banked or put out. The pay of the employees goes on, but no work has been done for the money, and the only decrease in cost is the slight amount of coal and

Mr. Bailey. oil saved by not operating the pumps. With the filter area subdivided, and only one unit out at a time, either the operating portion may be forced to yield the desired quantity of water, or else the only loss, in addition to the lessened quantity, will be a decreased duty of the pumping engines. The loss in efficiency of the filter, due to a moderately increased rate of flow, will not be material, provided proper judgment and care is, and has been, used in starting and operating the beds.

At Albany it has been found to be a mistake to not entirely drain a bed before cleaning. The water should be completely off the sand surface, and, in the slight depressions which always occur in the surface, no puddles should be left. With a dry surface, the cleaning is done more quickly and more thoroughly. With a wet bed, the men are apt to slight the surface underneath the water, and the escape of the water from the shovel as it is lifted, carries a portion of mud and slime with it, which runs down into the sand, and the result is a bed which is unclean in spots and which will cause uneven rates of filtration. A bed thus scraped always makes a short run between scrapings.

All the plants named are defective, in that they depend upon manual labor for all handling of sand between scraping the bed and refilling it. There is no good reason why a movable ejector hopper should not be utilized, and, after the sand is scraped into piles, it should be shoveled into this hopper, and thereafter not again touched with the shovel or barrow until it is taken away from the sand washer, or deposited upon the bed. It is known that experiments are being made, and such an arrangement will be incorporated in some of the filters now contemplated or being designed, and the effect will be to reduce materially the cost of operating sand filters.

Mr. Wachter. LEONARD M. WACHTER, Esq.* (by letter).—In comparison with the quantities of water filtered at Lawrence between successive scrapings, it is thought that the following facts and the diagram (Fig. 6) showing what has been done at Albany under the conditions met there will be of interest.

The water of the Hudson at the Albany plant is comparatively clear for, probably, at least 75% of the time. During the year 1900 there were 71 days when the turbidity was 0.100 and over (wire-method, reciprocal scale). Turbidity reaching this figure is caused by heavy rainfall over a large portion of the water-shed, and by thaws and spring freshets. The suspended matters consist of silt and, also, considerable clay at times.

Table No. 30 shows the length of service, quantity filtered per acre, and turbidity of the raw water for Filter No. 8, from the start, July 27th, 1899, until May 18th, 1901.

That it is a fair average, is shown by the following: The average

* Chemist in charge of Albany Filter-Plant.

Mr. Wachter.

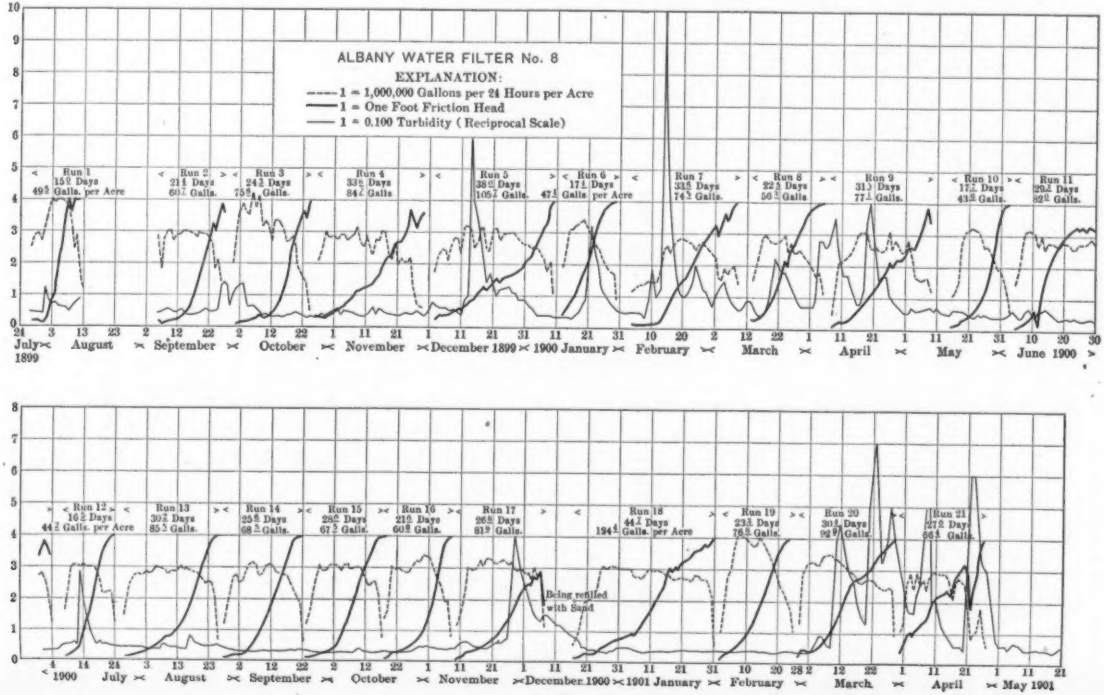


FIG. 6.

Mr. Wachter. length of runs for all filters up to December 29th, 1900, was 25.8 days. The average quantity filtered per acre between scrapings was 70 000 000 galls. For the filter tabulated the average length of run was 25.9 days. The average quantity filtered per acre was 71 200 000 galls. The average rate while in operation was 2 750 000 galls. per acre per twenty-four hours.

TABLE No. 30.

Number of run.	Date of starting.	Date of end of run.	Length of run, in days.	Millions of gallons per acre.	Maximum turbidity.	Number of days during which the turbidity was 0.100 or over.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	July 27	Aug. 12	15.0	49.5	0.120	1
2	Sept. 6	Sept. 27	21.4	60.7	0.140	2
3	Sept. 30	Oct. 22	24.3	75 8	0.130	3
4	Oct. 27	Nov. 29	33.6	84.2	none	none
5	Dec. 3	Jan. 10	38.0	105.8	0.600	16
6	Jan. 13	Jan. 30	17.5	47.4	0.320	7
7	Feb. 4	March 9	33.6	74.5	0.900	24
8	March 14	April 5	22.5	56.3	0.280	10
9	April 8	May 9	31.5	77.0	0.400	18
10	May 16	June 4	17.7	43.6	none	none
11	June 5	July 4	29.3	81.9	none	none
12	July 8	July 24	16.5	44.2	0.290	3
13	July 27	Aug. 26	30.2	85.5	none	none
14	Aug. 28	Sept. 22	25.4	68.5	none	none
15	Sept. 23	Oct. 17	23.7	67.5	none	none
16	Oct. 18	Nov. 8	20.8	59.9	none	none
17	Nov. 10	Dec. 7	26.6	81.6	0.400	11
18	Dec. 17	Jan. 31	44.7	124.4	none	none
19	Feb. 2	Feb. 25	23.3	76.8	none	none
20	Feb. 27	March 29	30.4	92.9	0.700	20
21	March 31	April 27	27.0	66.4	0.600	21
22	April 30	May 18	17.5	41.2	none	none

Runs Nos. 7, 9 and 20 (see Fig. 6) were during periods of the highest turbidity of quite long duration, and delivered above the average quantities between cleanings, while Runs Nos. 10 and 22, following periods of high turbidity, are two of the lowest quantities filtered. This would seem to show that the yield of runs succeeding periods of high turbidity is materially reduced, while the runs during periods of high turbidity are not noticeably shortened. Observations of the condition of the beds at such times show that the mud penetrates the sand in considerable quantities for a distance of about 2 ins., and, as it is not practicable to remove this amount of sand at one scraping, it evidently forms the nucleus for resistance, and the yield of the succeeding run is reduced.

Run No. 12 was probably reduced by micro-organisms in the raw water, as the time of the year was favorable.

Run No. 17 was not completed. It was necessary to scrape the

filter so as to refill sand into the bed to clear the court yard before the advent of winter. Mr. Wachter.

Run No. 18 was directly after refilling. and this fact, with the absence of high turbidity and the favorable season of the year, made this the largest yield from any filter.

M. F. COLLINS,* Esq.—Inasmuch as certain criticisms have been made at various times in regard to the excessive cost of operating the Lawrence City filter, as compared with the expense of maintenance of sand filters at other places, it has seemed fair that the conditions producing this result should be given in some detail. Mr. Collins.

The speaker does not intend to discuss general matters of interest, but will simply confine his remarks to a statement of some of the conditions of operation which have occurred at Lawrence. Some of these are entirely local, and are due to the arrangement of the filter plant, while others, such as non-covering and climate, appear to exercise a greater influence here than at most other places where filters are in operation.

CONDITIONS DUE TO OPEN SURFACE.

Disturbance of Work by Rain.—During the period that the speaker has been in charge of the filter. he has found that the occurrence of rain storms plays an important part in increasing the cost of maintenance. Occasionally, when draining the filter during the night, in order to have it ready for scraping the next day, a rain storm has come up and has effectually prevented all work, the yield of filtered water meanwhile being entirely cut off and so remaining until the weather had cleared and the filter had been scraped and again placed in service.

Moreover, it has sometimes happened that while scraping the filter with a large working force, a heavy shower, or possibly a more extended rainstorm, has suddenly blown up before the piles of scrapings had been wheeled out. This has caused an abandonment of the work, the laborers being retained under pay with the expectation of an immediate clearing in the weather, which might or might not quickly happen, causing an increased cost of scraping. Occasionally, the necessity of securing water has compelled the men to return to work, notwithstanding the rain, if this is long continued. This latter condition is of itself extravagant, inasmuch as the sand, while wet, is in all ways much more difficult to handle. It will be seen, therefore, that rainy weather during times of scraping necessitates an increased cost of this operation.

Necessity of Removing Snow and Ice.—When extreme cold weather sets in, the whole area of the water surface freezes, oftentimes to depths of from 8 to 12 ins. In order to scrape a section of the filter at such

* Superintendent of Lawrence Water Department.

Mr. Collins. a time, the ice, together with any snow which may be upon it, must first be cut and removed, usually on the day before draining. In cold weather an additional coating of ice, sometimes 1 in. or more in thickness, forms before the filter is entirely drained, causing an increased cost and delay in scraping.

Difficulty Caused by Thin Ice on Sand Surface.—After a section has been made free from ice, and draining is being carried on, a thin ice layer forms upon the water surface during cold weather, and, lowering with the water, descends to the sand surface and becomes frozen to it. Scraping is thus rendered very difficult, and the amount of material removed is largely increased, on account of the ice and the necessity of scraping deeper. Those who have had experience in cleaning filters of this sort can readily appreciate the trouble from these conditions, and the increase in expense of scraping caused thereby.

Difficulty Caused by Snow.—During the winter serious difficulty in scraping and conveying is caused by light falls of snow. However light the snowfall, if the sand surface is covered, the depth to which scraping should be carried on cannot be gauged as accurately as in clear weather, and it has been found by the speaker that there is invariably a tendency to scrape too deeply with the shovel. This circumstance is very trying when every effort is being made to reduce the cost of maintenance, but there seems to be no method of preventing it, inasmuch as laborers require long experience in this work to enable them to know to what depth to carry the shovel during the various conditions of scraping.

Difficulty Caused by Freezing of Sand Surface.—During the early and late portions of the winter, even when the weather is not cold enough to freeze the water surface to any extent, it sometimes is capable of producing frost in the filter sand after draining to a considerable depth. Even a depth of freezing not greater than 1 in. causes an increase in the amount of sand which it is necessary to remove, and consequently an increase in the cost of scraping.

Conditions Arising from the Lack of a Convenient Storage Place for Scraped Sand.

Conveying sand from the filter is always an expensive operation, but especially so in winter, on account of the lack of a convenient place in which to store the scraped material after it has been removed from the bed.

The lower roadway bordering upon the north side of the filter is utilized as a temporary dumping ground, where sand remains over night or until it can be removed during the following day or days to the permanent place assigned for dirty sand in the neighborhood of the washing machine. During cold weather this deposit of sand becomes frozen, and extra labor is required to break it up and get it

into condition for removal to the permanent dump. This double handling is, of course, expensive, but seems to be necessary under present conditions, due to the peculiar location of the filter. With suitable conveying apparatus the cost of this item of maintenance could doubtless be reduced in very large measure. Mr. Collins.

CONDITIONS DUE TO THE CONSTRUCTION OF THE FILTER IN ONE UNIT.

In the last annual report of the Lawrence Water Board, for the year 1900, the speaker recommended that two transverse division walls be placed in the filter, making three filtering sections of about equal area. If this work be done it will greatly facilitate the operation of the filter, and thereby lessen the cost of maintenance. One section may be cleaned at a time, while the other two may be operated as usual. With this construction, the comparatively small force of men now required for the routine work of maintenance would also be sufficient for the performance of scraping, which it has been shown is not now the case. Moreover, the permanent force of laborers will individually become more skilful in performing all the operations devolving upon it. The importance of this last feature can scarcely be over-estimated. In the process of scraping alone a great saving can be effected, as green men usually go from $\frac{1}{2}$ to 1 in. deeper than is necessary in the process of scraping. It will be seen that the effect of the increased quantity of material thus removed is to increase, not only the cost of scraping, but also of conveying, washing and sanding.

The speaker has thus briefly outlined some of the leading obstacles which occur in the operation of open sand filters, constructed as a single unit, in a climate where the winters are variable and often severe. He trusts that these suggestions may be instrumental in bringing out a discussion of similar problems confronting the practical operations of other filtration works, and that they may serve to suggest opportunities for improvement in designing other plants.

GEORGE W. FULLER, Assoc. M. Am. Soc. C. E.—This paper is a welcome addition to the literature upon water purification, in that it brings together for ready reference the leading information from various reports and records relative to the Lawrence filter, and especially in that it places on record more comprehensive data concerning the operation of the plant than have been readily available hitherto. Mr. G. W. Fuller.

This filter holds a unique position among municipal works, and engages especial attention, not only from engineers, but from workers and students in various sanitary lines. To appreciate fully the position which the Lawrence filter occupies, it is necessary to consider with some care the conditions which were associated with its installation. Looking back nine years, and from the standpoint of our present knowledge, it might seem at first sight that there was nothing remark-

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able about the installation of a plant for the purification of a municipal water supply amounting to about 3 000 000 galls. daily.

In 1892, when the construction of this plant was begun, however, the entire subject of water purification was in a state much less clearly crystallized than at the present time. It is true that important studies had been made in the application of the germ theory of disease to problems in epidemiology, and also in the application of bacteriology to questions of water purification. At the Lawrence Experiment Station, furthermore, there had been in operation for some months a series of experimental sand filters for the purification of the Merrimac River water, from the studies of which were discovered some of the more important laws of filtration under the conditions which there existed.

In spite of all this, it was a period of much uncertainty and of many marked differences of opinion. Comparatively little progress of a substantial nature had been made for some time in the field of water purification in Europe, and in the United States the subject had laid almost dormant for twenty years, so far as the installation of municipal plants was concerned. The technical journals of Europe had much to say concerning the outbreak of typhoid fever during the winter of 1889 in the eastern portion of the City of Berlin, where the water consumers were supplied with filtered water from the old Stralau sand filters, which were operated on the continuous method. At London a Royal Commission was engaged in an investigation of the future supply for the Metropolitan District, and received testimony from prominent professional men to the effect that the filtered Thames water should be abandoned and replaced by new supplies from mountain sources. In a number of the larger cities of Europe vigorous discussions were occurring with regard to the urgent need of providing municipal supplies only from unpolluted mountain streams or from ground-water. In this country a few scattering mechanical filter plants had been installed; but the available evidence as to their hygienic efficiency was not favorable. Sanitarians were disposed to give to filtration in general less credit than it really deserved, and engineers were sceptical as to its practicability in many cases on the ground of its cost.

In the Merrimac Valley several of the larger cities, including Lawrence itself, had for several years suffered severely from epidemics of typhoid fever. It will also be recalled that late in the summer of 1892 Asiatic cholera appeared in New York Harbor. Under these experiences and conditions there was full recognition on the part of the Lawrence city government that cholera might become established temporarily in the cities located above them in the Merrimac Valley, and that, if so, their water supply must either be purified or cut off. They acted wisely and promptly in placing at the disposal of the Water Board such sums of money from their limited available means as

would enable to be carried out the recommendations of the State Board of Health, whose advice they had sought. Mr. G. W. Fuller.

It is said that it is frequently darkest just before the dawn, and subsequent developments show that such, in a measure, was the case in the instance not only of the Lawrence water supply, but of the entire subject of pure water and of water purification throughout this country. It is difficult to estimate readily how great has been the benefit which this filter has produced outside of the City of Lawrence. It has proved a stimulus and an example for many later developments in this field, and it has served as a basis of reference for engineers and sanitarians, not only in this country, but also in Europe. No matter how many filters may be built in years to come, which are larger in capacity, or more efficient or more economical in operation, it is very doubtful if any will succeed in displacing the Lawrence filter from the classical position which it now securely holds as marking the beginning of a new epoch, and in fact the first epoch of important practical accomplishments, in this country, in water purification.

The authors of this paper commence their description of the filter with the statement that it was designed by Mr. Hiram F. Mills, Chairman of the Committee on Water Supply and Sewerage of the State Board of Health of Massachusetts. To the thought of the speaker, this hardly tells the whole story. It is true that the State Board of Health advised the city government with regard to the adoption of a filter, and that its construction was commenced under the general direction of the Board. Mr. Mills, however, in addition to his official connection with this project through the State Board of Health, also served in his individual capacity as Consulting Engineer to the Lawrence Water Board. Without compensation he designed this filter, based in a large measure upon the studies made at the Lawrence Experiment Station, and took the greatest interest in the carrying out of the project, even to the extent of loaning to the city some of his own assistants and foremen to aid in the work. In discussing the Lawrence filter the speaker cannot refrain from calling attention to the great debt of gratitude which is owed to this most distinguished engineer and public-spirited citizen, by the water consumers, not only of the City of Lawrence, but also of the entire country. It is to him, more than to any one else, that credit is due for installing and carrying on judiciously planned and carefully studied investigations, which have paved the way for many recent improvements in this branch of public service.

One of the most characteristic features in the design of the Lawrence filter consists in the fact that the entire filtering surface is unbroken by any division walls, such as are provided in practically every other municipal filter, in order that a portion of the plant may be thrown out of operation for cleaning or repairs, while the remain

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ing portion continues in service. This arrangement at Lawrence was made possible by the size of the plant, and by the fact that the filter was to be operated intermittently, a method which at that time Mr. Mills thought to be superior to continuous filtration.

In order to secure reasonably uniform rates of filtration through recently scraped portions of the surface, as compared with the remainder of the filter, the sand and gravel layers were designed in a most ingenious manner, as is shown in Fig. 2. This arrangement of the gravel layers, together with the use of a sand layer of different sizes and of varying thickness, according to the distance from the collecting pipe, obviously restricts the flow of water which would naturally pass through the area of clean sand surface of any one of the 25 sections that form the filter. It was provided in the design that the loss of head in this filter should not normally exceed about 2 ft., and that a portion of the filtering surface should be scraped each day, the area of that portion being such that the entire surface would be scraped about once a month. Under these conditions the restrictions in the exit passages for the filtered water were designed to be such that it would be impossible to secure a rate of filtration of more than about 5 000 000 or 6 000 000 galls. per acre per 24 hours through a recently-scraped portion of the filter surface. Further, as only about one-twenty-fifth of the entire surface would be scraped at a time, under ordinary circumstances, as originally provided for, the comparatively slight deterioration in the water filtered at this increased rate would be very largely offset by dilution with the filtered water coming under fairly normal conditions from the remaining portion of the filter. Thus, the filter was designed to serve as its own controller, within certain limits, and to offset by itself the results of differences in the amount of sediment deposited upon the surface. This feature is mentioned because it seems to be a point which is not very widely appreciated.

As is generally known, the Lawrence filter, for various reasons, has not been regularly operated in accordance with the original instructions, and in fact during the winter season it is almost impossible to carry out exactly the normal plan of procedure in the absence of a cover. Notwithstanding this, the results as to the quality of the filtered water are such as to show that as a general proposition Mr. Mills' design is a successful one for the purpose for which it was intended. Taking up the matter in specific terms, practically no data have been published to show how uniform the rate of filtration is over the different portions of the filter which have been cleaned at various times. About the only point which is known, in addition to the general success of the arrangement, refers to the somewhat higher rates of filtration which follow scraping in that portion of the filter which is nearest to the pumping station.

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How much of a factor the presence of ground-water or of water filtered through the bottom from the river has been with reference to the clogging of the underdrains, due more or less to dissolved iron, is unknown to the speaker. Taken in connection with the very complete draining which the filter receives from time to time, it would seem that water other than the filter effluent was associated with the complications which were mentioned in the 1898 report of the Lawrence Water Board, and which were referred to in the report of the State Board of Health for 1898, on page 26.

The use of two grades of sand in a water filter is quite unusual, and is, of course, accounted for as a part of the method adopted for preventing excessively high rates of filtration through recently-scraped portions of the filtering surface. It is noted that the two kinds of sand are specified in Fig. 2 according to their effective size, as is the usual custom at present, and not with regard to the "maximum rate" of the sand, as was the case on the original drawings and in the earlier reproductions. By "maximum rate" is meant the quantity of water in millions of gallons per acre daily which a sand, when clean, will allow to flow through it when the acting head is equal to the thickness of the sand layer, and the temperature of the water is 50° Fahr. Numerous observations* have been made showing that the friction of a sand to the flow of water increases very materially as the sand continues in service. In fact, it is quite uncertain what coefficients for different conditions should be used for converting effective size into maximum rate. Much assistance in the future will be secured if more attention be paid than at present to the maximum rate which sands of a given effective size offer to the flow of water in a filter as they are continued in service.

Although the Lawrence filter is still unprovided with a cover, the advantages which would result from the operation of this filter during winter weather if it should be covered are so apparent, both from the standpoint of economy and of uniformity in the hygienic efficiency of the filter, that there is practically nothing to be said on the discussion of this point.

With regard to the method of intermittent operation of the Lawrence City filter, it was considered at the time it was designed that, at least during some portions of the year, the amount of atmospheric oxygen dissolved in the Merrimac River water might prove inadequate to facilitate to a desired degree the nitrification of the organic matter contained in the water and stored in the filter, unless supplemented by air admitted to the filter by draining the sand. Exhaustive studies at a later date showed that for this river water artificial aeration is not needed, because, practically without exception, the effluents are found to contain sufficient oxygen for nitrification processes.

* See the paper by Mr. H. W. Clark, in the 1894 Report of the Massachusetts State Board of Health, p. 706.

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In the investigations made elsewhere in this country it is found that the organic matter contained in river waters used for public supplies is of such a character as to stability that nitrification is now considered as a general proposition to be much less of a factor in water purification than it was ten years ago. Many river waters contain more organic matter than the Merrimac at Lawrence, but very few contain so much of an unstable nature such as is caused by very recent sewage pollution, and which is capable of being readily acted upon by the bacteria. Present evidence indicates that intermittent filters will never find extended use in water purification, on the ground that if a water contains so much unstable organic matter that the oxygen which it contains naturally, and also by aeration before application to the filter, is inadequate for normal bacterial actions, then such a water should not be considered favorably for a public supply.

The intermittent method of operation possesses two distinct disadvantages. One refers to the vertical channels produced in the sand layer, due to escaping air upon filling the filter after draining, and which has a tendency to lower the bacterial efficiency of the plant. The other refers to the air which remains entrained in the sand layer, and which increases the friction offered to the passage of the water. This latter point affects the cost of operation by increasing the amount of sand to be removed to relieve clogging. It also increases the cost by reducing the capacity of the plant below the normal (for continuous filters) after it has been in service for some years.

In the Lawrence City filter the effect of air in the pores of the sand has shown itself less in reducing the bacterial efficiency than it has in increasing the amount of sand to be scraped from the surface. The influence of the channels through which the water could pass without adequate purification is very likely disguised by other factors in this large plant. It certainly was well-defined in the 16-ft. experimental filter at the Experiment Station, as will be noted by comparing the records of Filters Nos. 3 *b* and 8 *a* in the Reports of the Massachusetts State Board of Health. These two filters were put in operation at about the same time as the city filter, and contain the same kind of sand. No. 3 *b* was operated intermittently, and No. 8 *a* continuously. A summary of the leading results from the operation of the city filter and of these two experimental filters, receiving practically the same water, up to January 1st, 1900, is shown in Table No. 31.

From this summary it is seen that the intermittent filters did not surpass the continuous filter in the removal of organic matter or of color, while they gave a somewhat less satisfactory bacterial removal, although the differences all come within about one-half of 1% of the numbers in the applied river water. It will further be noted that the intermittent experimental filter gave a distinctly smaller yield of filtered water between scrapings than did the experimental continuous filter; and that

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the intermittent city filter gave much smaller yields than the experimental filters, thus increasing materially the volume of sand to be removed per million gallons of effluent. Although the sand removed from the small filters is very likely less than would be the case with any municipal filter operating on this water, it is considerably in excess of the amounts removed in some European filters operating upon very clear water.

TABLE No. 31.—SUMMARY OF LEADING RESULTS OF OPERATION OF WATER FILTERS AT LAWRENCE, MASS., FROM SEPTEMBER, 1893, UP TO JANUARY, 1900.

	City filter.	No. 3 *b*.	No. 8 *a*.
Kind	Intermittent.	Intermittent.	Continuous.
Area (acres)	2.44	0.005	0.005
Date of completion, 1893	Sept. 20.	Sept. 23.	Sept. 26.
Million gallons of water filtered	6 960	26.8	31.6
Average yield, in million gallons per acre daily	1.25	2.35	2.77
Total number of complete scrapings	79	86	79
Average number of days between scrapings	29	26	29
Average number of scrapings per year	12.6	13.8	12.6
Average yield per period between scrapings, in million gallons per acre	36	62	80
Estimated total amount of sand removed by scrapings { Thickness, in inches	59	42.5	42.0
Estimated total amount of sand removed by scrapings { Cubic yards per acre	8 000	5 700	5 600
Estimated average thickness of sand removed by scraping, in inches	0.75	0.49	0.53
Average volume of sand removed, in cubic yards per million gallons of effluent	2.79	1.06	0.89
Average color in applied water	0.43	0.41	0.41
Ditto in effluents*	0.38	0.29	0.29
Percentage of color removed	12	29	29
Average nitrogen as albuminoid ammonia in applied water	0.199	0.086	0.186
Ditto in effluents	0.094	0.189	0.088
Percentage of albuminoid ammonia removed	53	52	53
Average number of bacteria per cubic centimeter in applied water	9 000	9 000	9 000
Ditto in effluents*	95	65	45
Percentage of bacteria removed	98.9	99.3	99.5

* Excluding results of first month of operation.

In the paper a statement is made as to the estimated average amount of suspended matter which the Merrimac River water contains, namely, 10 parts per million. This figure is approximately correct, but it does not give an adequate idea of the capacity of this river water to clog a sand filter, when compared with the turbidity of western and southern waters. It is the suspended organic matter, of a more or less gelatinous nature, which acts as an important agent in clogging the filters to which the Merrimac River water is applied. To record properly the clogging powers of a water, a method should be devised which should include in a correct manner not only the turbidity due to suspended silt and clay, but also that due to organic

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matter. Obviously, a small weight of the latter, forming as it does a gelatinous film at and near the sand surface, does as much clogging as a much larger weight of mineral matter which produces a more granular appearance upon the sand surface.

The clogging in the Lawrence City filter appears to be caused, to a large degree, by the air entrained in the sand. This is made plain in Table No. 32, in which the leading data of operation of the Lawrence filter, as given in the paper, are compared with the data from the Mount Vernon filters, as given in *Engineering News*, May 30th, 1901. As a matter of general interest, the data from the Albany filter, as given by Mr. Bailey in *Engineering News*, August 7th, 1900, are also included in the comparison. It is not intended that these Albany data should be regarded as representative of that plant, as doubtless Mr. Bailey will soon publish the detailed evidence to date. While in a number of instances these results are only approximations, it is believed that they are sufficiently correct for present purposes, and that the averages are free from serious error. In both the Lawrence and Mount Vernon filters the costs are exclusive of charges due to removal of ice and snow. Fixed capital charges and the cost of analytical supervision are not included in the case of any of the plants.

TABLE No. 32.—Comparison of Approximate Average Results and Costs of Operation of Water Filters.

Filter	Lawrence.	Mt Vernon.	Albany.
Area, acres	2.44	1.1	5.6
Period included in averages	1896-1900	1897-1900	1899-1900
Million gallons of water filtered	5 820	2 740	3 570
Yield in million gallons per acre, daily	1.3	1.7	2.6
Total number of complete scrapings	75.	61.	9.6
Number of days between scrapings	24.	24.	25.
Number of scrapings per year	15.	15.	15.
Million gallons of effluent per acre between scrapings	32.	41.	66.
Cost of scraping per acre	$25.80	$....	$17.50
Cost of wheeling out per acre	69.00	....	35.20
Sum of scraping and wheeling out	94.80	66.65	52.70
Thickness of sand layer removed per scraping, in inches	0.75	0.61	0.71
Cubic yards of sand removed per acre per scraping	100.	82.	95.
Cubic yards of sand removed per million gallons of effluent	3.14	2.00	1.44
Cost per cubic yard for scraping and wheeling out sand	$0.95	$0.82	$0.55
Ditto for washing sand	0.47	0.33	0.40
Ditto for replacing sand	0.28	0.36	0.43
Sum of cost per cubic yard of handling sand	1.70	1.51	1.38
Ditto per million gallons of effluent	5.36	3.03	1.98
Miscellaneous and general expenses per million gallons	0.56	0.11	0.19
Total cost of operation per million gallons of effluent, exclusive of ice	5.92	3.14	2.17

In regard to the relative costs of scraping the filters and of wheeling out the dirty sand, this information is not available for the Mt. Vernon filters. At the Lawrence filter it is to be recalled that

wheeling out the sand involves two handlings of the material, it being first wheeled to a temporary dump at the side of the filter. Mr. G. W. Fuller.

In studying these data it is seen that the cost per cubic yard of sand, for scraping, wheeling out, washing and replacing in the Lawrence filter is only about 10% in excess of what might be called a normal charge, notwithstanding that the total cost of operation, exclusive of ice, is more than double the sum found by European experience with American rates of wages, and as found in several places in this country. The chief difference is found in the large volume of sand removed per million gallons of effluent; and it seems to be a logical conclusion that this feature, due evidently in a large measure to clogging caused by entrained air, is the principal explanation of the high cost of operation of the Lawrence filter.

Although the cost of filtration at Lawrence is above the normal for this type of water, this question becomes a matter of relative insignificance when we consider the great work which the filter has accomplished in reducing typhoid fever in this city. During the past five years, excepting a few weeks following the special repairs in the underdrains, the annual death rate from this disease has been less than 20 per 100 000 inhabitants, a rate which for American cities is about as low as can be expected in cases where public water supplies are drawn from unpolluted sources. This record is the greatest testimonial which can be paid to the splendid results accomplished by the Lawrence City filter.

In their discussion of the typhoid statistics of Lawrence, the authors neglect to call especial attention to the low death rate which the city now enjoys, and confine their comments to the percentages of reduction of typhoid fever based on the records before and after the installation of the filter. These comparisons are of interest, but they have their limitations, as typhoid data seem to move more or less in cycles of uncertain lengths. While the authors are correct that had the filter not been erected at Lawrence the typhoid rate would possibly have been less during the past seven years than during the preceding period of that length, the reason is not to be found in a study of the general records of the State of Massachusetts, but in those of the Merrimac Valley above Lawrence. Notwithstanding the fact that the general pollution of this river is steadily increasing year by year, it is true that there has been a reduction in typhoid fever in those cities above Lawrence which sewer into this river or its tributaries. The reason for this is almost solely due to the marked reduction in typhoid fever at Lowell, following the introduction of a ground-water supply. In fact, in the remaining cities in the upper Merrimac Valley, as far as the speaker has been able to ascertain, the rate of increase of population has, on an average, more than offset such decreases as have occurred in the typhoid fever death rates.

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Referring to the relationship which the filter has brought about between the removal of bacteria from the Merrimac River water and the removal of typhoid fever, it will be noted that, in round numbers, this filter, on an average, has effected a removal of about 99% of the bacteria in the applied water. In this connection the speaker desires to call attention to the fact that in 1891, when the typhoid fever rate in Lawrence was highest, there was a removal of from 90 to 95% of the river water bacteria as the water passed through the distributing reservoir and piping system of the water-works. In the early winter of 1898-99, following the repairs on the underdrains, and when a mild epidemic of typhoid fever appeared, the filter, on an average, effected a removal of about 93% of the river water bacteria. To those who are inclined to the opinion that in the case of sewage-polluted waters it is a matter of indifference whether or not a filter is carefully operated, the records from Lawrence will furnish much food for reflection.

Mr. Soper.

GEORGE A. SOPER, Assoc. M. Am. Soc. C. E.—This paper is accorded a warm welcome in the mind of the speaker, for two principal reasons. First, it is valued for its intrinsic merit; it is full of carefully collected facts, and these are set forth in a way which gives ample assurance that the authors desired to collate their information in an intelligent and impartial manner. The paper is also peculiarly acceptable to the speaker for the opportunity it affords him to make a few inquiries under circumstances which seem to insure their full answer.

Seeming Inconsistency Between the Filter and its Results.—A few years ago, when the speaker was engineer for one of the mechanical filter companies, it was considered part of his business to answer some of these inquiries regarding the Lawrence filter. The question usually originated with laymen, who, as delegates of municipalities, or representatives of water companies, were investigating the relative merits of slow and rapid filters, and who had passed through the hands of those who knew how to say a good word for slow filtration. They had heard a great deal about the excellent results at Lawrence, and were a little confused as to how those results were obtained. The speaker's principal interrogatory, therefore, is, what are the conditions upon which the efficiency of the Lawrence filter especially depends?

Basing a knowledge of filtration upon principles and precepts founded very largely upon the classic experiments made at Lawrence for the Massachusetts State Board of Health, it has sometimes been considered that in construction and operation the Lawrence filter is not one from which superior results could be expected. The facts at first laid down as necessary to its success, seem to have been disregarded in actual practice. Thus, for example, it was stated by the engineer of the works that one of the essential qualities of the design requires that the inlet water shall be shut off once a day, and the

pump kept running until the sand is uncovered and the water within the sand drawn out, so that the sand can fill with air from top to bottom. This was a condition made necessary by the principle of intermittent filtration. Again, it was intended to clean a portion of the bed every day, and this portion, when cleaned, was said to be incapable of conveying so large a quantity of water that it could not be properly purified in its passage, unless there were an extreme drawing down of the head, which would require close watching at the pumps. Mr. Soper.

In recent years it has been customary to operate the Lawrence filter in a manner which has been described by the authors as not intermittent, but practically continuous, and they state that it has made very little difference in the results.

It is learned from the paper that there has been a great deal of drawing down of the head, and it seems there has not always been a very close watching of the pumps. Yet chemical and bacterial evidence is not wanting to show that the quality of the effluent is not seriously affected by these seeming departures from original principles. The peculiar features of the plant are not restricted to the points named. In the Lawrence works we have a filter operating at 5 000 000 galls. per acre per day, instead of the 2 000 000 to 3 000 000 galls. generally accepted as the proper limit. We have a filter which is stopped and started every day instead of one which is run at a uniform rate for periods generally exceeding a month. The sand is never equally clean or dirty over the whole area; from which it would seem that, different parts of the bed being more or less clogged, and so offering unequal degrees of resistance to the flow of water, different rates of filtration and not a uniform rate would necessarily be obtained through the bed. No period of rest is given the clean filter for the formation of a coat of *schmutzdecke*, nor is the first of a new effluent thrown away as likely to be impure. After cleaning the bed, raw water is poured down on the filter until the sand is flooded; filtered water is not backed up under it. Then, the sand is not of uniform depth; the differences in depth are intended to be made up by differences in the size of the grains of sand, so that uniformity in filtration further depends on a nicety in adjusting the filtering material. These are all unusual features for a slow filter, and the peculiar success which seems to have attended the plant consequently calls for a few words of explanation.

How are the excellent results accounted for? Apparently, either on the basis that, in the past, the laws of filtration have been observed more narrowly than necessary, or that the Lawrence plant has elements of advantage which are not ordinarily taken into account. The speaker is aware that recent facts from the Lawrence Experiment Station throw light on some of the points referred to, and his experience with water filters assists in reconciling others, but it would be interesting to hear from some of the gentlemen who have been connected with the Law-

Mr. Soper.

rence works, as to how, in general terms, they regard the apparent inconsistencies pointed out between the filter and its results.

Indications of Ground-Water in the Effluent.—Leaving the question as to how the principles elsewhere understood to control efficiency in slow filtration have bearing upon the operation of the Lawrence plant, the speaker desires to call attention to a feature which has not been touched upon by the authors, but which may have some influence in bringing about the excellent results attributed to the filter. It is desired to ask how far the accidental inflow of ground-water, or infiltration of river water to the bottom of the filter, may affect the results. The length of the filter excavation is 750 ft., with a width of 140 ft., and it lies within an initial distance of 50 ft. from the river. The bottom of the filter bed is understood to be unpaved, and open to the inflow of such water as may be present from 6 to 8 ft. below the level of low water in the river. The paper does not state the character of the excavated material, but it is stated that the old filter gallery which runs along the filter on the land side, was built in a stratum of coarse gravel. The gallery was 300 ft. long and was located 200 ft. from the river. It was tested in September, 1877, and found to be able to collect 275 000 galls. of water per day. When the filter was built the infiltration gallery was incorporated with it, and is now used as a conduit to carry the filter effluent to the pumps. The length of the infiltration conduit has been extended to a total length of 710 ft. in a direction previously regarded as one likely to develop a considerable amount of ground-water.

The question occurs here: How much of the Lawrence water is filtered, and how much is ground-water? The results of chemical analyses of applied Merrimac River water and effluent from the Lawrence filter for the years 1893 to 1899 have a bearing upon this point. The data are given by the authors in Table No. 17. Examining the determinations of those dissolved matters which, under ordinary circumstances, are little if at all affected by filtration, it is found that the river water is purer than the effluent. The figures which represent chlorine and hardness are remarkable; the average increase in these matters being 9.1% and 50%, respectively. The total solids are increased 33.6 per cent. If, from the data for total solids, is subtracted the average weight of suspended matter found in Merrimac water, the increase in the amount of dissolved solids which appear to result from filtration is 78.8 per cent. Even if a liberal allowance is made for the conversion of organic matter into mineral matter, which generally takes place in well-operated filters, there is still a heavy increase of solids to be accounted for. It is possible that the sand parts with some of its mineral matter to the water which passes through it, but many considerations render it unlikely that so great an increase in dissolved matters, and especially chlorine, could come

from this source. The conclusion seems irresistible that a considerable quantity of ground-water finds its way into the drainage system of the filter plant. Mr. Soper.

The application of the point is obvious. It means, unless explained, that the filter is credited with filtering at a greater rate and with, perhaps, a higher bacterial efficiency than is actually the case. The presence of an uncertain, though possibly small amount of ground-water, or infiltrated river water, would affect the accuracy of the reports of the filter's action in such a way that those who have the interests of the case most at heart must have carefully collected information along this line. If so, the speaker would like to have some of it.

The Reduction of Bacteria.—The results of bacteriological analyses of the water pumped at Lawrence, indicate that comparatively few bacteria pass through the filter bed. The proportion removed is given as 99.1% for the last year. It is noticed that there has been a steady decrease in the number of bacteria found in the effluent since the filter was built. From an average of 150 per cubic centimeter in the effluent in 1894, after the filter had been put in good running order, the number of bacteria has run down to an average of 55 per cubic centimeter for the year 1899. During the same time the raw water appears to have improved in quality also. In the six years mentioned, the number of bacteria in the Merrimac River water at Lawrence has fallen from an average of 10 800 to 5 800 per cubic centimeter. It would be interesting to know how these decreases are accounted for, and whether they are to be at all ascribed to improved methods of bacteriological technique, or represent solely an improvement in the quality of the water. The question has bearing upon the actual number of bacteria present in the water pumped from the filter. This is an important point in water purification, as it is of less significance in the average case that a filter shall remove 99% of the bacteria, than that it shall leave only 50 or fewer organisms to the cubic centimeter.

Reduction in the Typhoid Fever Death Rate.—A word on the subject of typhoid fever, which is the ultimate and most crucial phase of the question before us: The Lawrence filter was constructed in 1893 to protect the people of Lawrence against typhoid fever, which was considered to be communicated to them largely through the medium of the public water supply. The death rate from typhoid fever at Lawrence for the six years prior to the construction of the plant averaged 12 per 10 000 of the population. For the six years following construction, the death rate from typhoid per 10 000 was 2.6. The difference is 78 per cent.

The authors very properly point out that this percentage of reduction is not to be ascribed solely to the operation of the filter plant.

Mr. Soper. Other factors combined to reduce the mortality. Lest there should be some misconception, the authors have indicated the nature of some of these influences. Thus, they state that one favorable factor lay in improved sanitary conditions, while another was better methods of medical treatment. To the speaker's mind, a very important factor lay in the educational effect produced by the great amount of attention which was called to the danger of drinking impure water at about this time. Letters were sent by the Massachusetts Board of Health to the Mayor of the city, notices were posted in the mills and public places, and there was a general campaign against the disease which had for some time been epidemic in various cities along the Merrimac River. As an evidence of the popular response to the warning against polluted water it is said that large quantities of bottled water were sold, and that many people boiled the city water before drinking it. Just how efficacious this educational factor may properly be considered to have been, it is impossible to say, but its effect in all probability, was very considerable.

It has been frequently stated that fluctuations in the number of deaths from typhoid fever at Lawrence followed similar changes at Lowell before the Lawrence City filter was built. A relation of cause and effect seems to have been firmly established in this matter by those who have carefully investigated the facts. Has this relation continued to the present time? Data relating to monthly variations in the typhoid fever death rates for the two cities are not at present accessible, but if the available statistics for the period from 1893 to 1899 are examined, a plotting of the number of deaths from typhoid fever each year together with the similar data from Lawrence will show a general correspondence in the curves. That is to say, there was a very notable decrease in each case at about the time the Lawrence filter was built. From 53 deaths at Lowell in 1893, there was a sharp decline to 18 in 1897; 24 in 1898, and 17 in 1899. Here there is an influence highly favorable to a reduction of the death rate at Lawrence which has apparently been overlooked. Using the last two factors referred to as conditions which contributed to a reduction in the typhoid fever death rate at Lawrence, it can hardly be denied that the number of typhoid fever victims would have been greatly decreased by the filter.

This leads to the question: What actual saving in life has resulted from the construction of the filtration plant? The authors consider, after deducting the effect of various influences and tendencies, that the filter has resulted in the prevention of the death of 40 out of every 100 persons who would otherwise have died of typhoid fever in Lawrence. That is to say, in a city of 62 520 inhabitants, the lives of 8 persons were saved from death last year. It is not the speaker's intention to ask that the figure given in this estimate be qualified or reduced. The question is not one that is susceptible of proof, but rests

properly as a matter of opinion. The saving mentioned, or half this saving, would amply justify the installation of a filter, but it is desired to ask of the gentlemen who have made a study of the Lawrence plant, how, in the face of so many seeming imperfections in construction and operation, such good results can be accounted for? Mr. Soper.

There is little doubt that these inquiries cover ground which is familiar to those who are intimately acquainted with the details of construction and operation of the plant under discussion, and that they are prepared to give full and complete answers to all questions which may be asked. It is hoped that they will regard the present inquiries as worthy of consideration, and that they will give the profession the benefit of the light which they, better than any others, are able to throw upon these topics.

GEORGE C. WHIPPLE, Assoc. M. Am. Soc. C. E. (by letter).—This paper, upon the operation of the Lawrence filter, is most interesting and complete, yet there is one subject to which the authors have not alluded, namely, the microscopic organisms and their growth upon the sand and in the filtered water when stored in the reservoir. The probable reason for the omission is that, unlike the experience of many cities with open filters, Lawrence has had no trouble from these organisms. Mr. Whipple.

TABLE No. 33.—NUMBER OF MICROSCOPIC ORGANISMS IN THE WATER OF THE MERRIMAC RIVER, AT LAWRENCE, MASS.

	1890.	1891.	1892.	1893.	1894.	1895.	1896.
January	....	3	....	7	15	14	3
February	11	55	16	38	20	45	5
March	....	....	5	53	56	20	12
April	16	9	109	19	49	46	12
May	8	101	153	93	126	434	145
June	45	119	247	289	461	1 690	225
July	310	320	160	346	165	1 163	356
August	113	678	82	175	469	708	142
September	19	79	88	113	139	108	58
October	71	43	58	88	83	85	12
November	5	34	29	10	25	40	6
December	7	19	11	15	4	2	47
Average	61	133	87	104	134	363	86

List of prominent organisms.	Number of times in which the organisms exceeded 50 per cubic centimeter.
Synedra	21
Protococcus (chlorococcus)	7
Fragilaria	2
Crenothrix	4
Tabellaria	2
Chroöcoccus	1
Selenastrum	1
Dinobryon	1

Mr. Whipple. As a rule, river waters do not contain large numbers of algæ, protozoa, etc., and the Merrimac River, at Lawrence, is no exception to this rule. The records of the Massachusetts State Board of Health show that, with the exception of *Synedra* and *Protococcus*, no organism has ever been present in numbers greater than 500 per cubic centimeter. Table No. 33, compiled from these records, gives the number of organisms during each month from February, 1890, to December, 1896, together with a list of the genera which have been observed in numbers greater than 50 per cubic centimeter, and the number of occasions on which this figure was exceeded.

TABLE No. 34.—NUMBER OF ORGANISMS, EXPRESSED IN STANDARD UNITS PER SQUARE CENTIMETER, UPON THE SURFACE OF CERTAIN FILTERS.

FILTER.	LAWRENCE CITY FILTER.	MOUNT VERNON, N. Y.	PITTSBURG, BED NO. 1.	POUGHKEEPSIE.
Date of Examination.	April 12, 1900.	April, 1900.	May 4, 1900.	April 10, 1900.
Diatomaceæ—				
Cyclotella	4 000	20 000	108 000	14 000
Gomphonema	4 000			
Melosira	32 000	80 000	12 000	
Navicula	4 000	30 000	6 000	21 000
Synedra	24 000	160 000	1 092 000	35 000
Tabellaria	4 000		12 000	
Asterionella		700 000		
Cymbella		10 000		
Fragilaria		50 000		
Eunotia				7 000
Surirella				7 000
Coscinodiscus				7 000
Ceratoneis				7 000
Meridion				14 000
Chlorophyceæ—				
Closterium		10 000		
Cosmarium		10 000		
Conferva				14 000
Cyanaphyceæ—				
Cœlosphœrium		150 000		
Oscillaria				14 000
Schizomycetes—				
Crenothrix		20 000	90 000	
Protozoa—				
Cyphoderia	4 000	10 000		
Ciliata		10 000		
Trachelomonas		10 000		
Vorticella		10 000		
Anthophysa				7 000
Rotifera—				
Amiræa		10 000		
Rotifer	4 000	10 000		
Other organisms—				
Nais	4 000			
Anguillula		10 000		
Chætonotus		10 000		
Total organisms	84 000	1 320 000	1 320 000	147 000

Not only are there comparatively few organisms in the applied water, but few organisms seem to grow upon the sand or in the water above the sand. With the filter operated intermittently, heavy growths

of algæ upon the sand would not be expected, as the drying of the sand surface would not be favorable to them. Recently, however, the filter has been operated continuously, thus giving opportunity for such growths to occur, but, even now, the *schmutzdecke* contains comparatively few organisms. During the year 1900, through the kindness of Mr. A. H. Salisbury and Mr. M. F. Collins, the writer had the opportunity of examining samples of scum from the Lawrence filter at frequent intervals. All the samples were noted for their paucity of microscopic organisms. The largest number was found on June 29th, 1900, after the bed had been in use 34 days. On that date there were 200 000 organisms per square centimeter of sand surface. The smallest number was 16 000 per square centimeter, on May 8th, after the bed had been in use 25 days. These figures practically represent the organisms strained from the water, rather than a growth on the sand, and are so low that they are far from being the controlling factor in determining when a bed must be scraped. It is probable that they affect, but little, the cost of scraping. In order to give an idea of the number of organisms that may be found upon the surface of a filter, Table No. 34 has been prepared from the examination of scum samples made during the year 1900. Mr. Whipple.

TABLE No. 35.—NUMBER OF MICROSCOPIC ORGANISMS IN THE WATER OF THE DISTRIBUTING RESERVOIR AT LAWRENCE.

	1890.	1891.	1892.	1893.	1894.	1895.	1896.
January	9	10	11	20	0	23	0
February	7	9	23	4	2	24	904
March	4	7	24	2	78	4	1 386
April	27	24	69	55	85	604	5
May	7	12	66	74	14	85	0
June	19	10	12	40	1	57	44
July	202	196	74	135	214	136	156
August	46	56	70	91	189	27	8
September	57	26	52	147	570	1 717	22
October	90	143	12	10	464	2	120
November	60	47	31	12	7	21	20
December	37	33	5	1	4	0	10
Average	47	48	37	49	135	225	223

List of prominent organisms.	Number of times in which the organisms exceeded 50 per cubic centimeter.
Crenothrix (leptothrox)	6
Protococcus (chlorococcus)	12
Synedra	2
Cyclotella	1
Botryococcus	1
Anabœna	1

At times the numbers rise to 5 000 000 and even 10 000 000 per square centimeter. Even in covered filters, as at Albany, N. Y.,

Mr. Whipple. and West Superior, Wis., numbers of more than 1 000 000 are sometimes obtained. At West Superior *Crenothrix* forms the bulk of the growth.

Apparently, there has been no trouble from growths of microscopic organisms in the filtered water when stored in the distributing reservoir. This reservoir is 694 ft. long, 375 ft. wide and 25 ft. deep, and has a capacity of 40 000 000 galls., or about 14 days' supply. Yet, with this comparatively long storage, the numbers of organisms in the reservoir water have been singularly low. Table No. 35, compiled from the published reports of the Massachusetts State Board of Health, shows that no extensive growths have occurred.

No results have been published since 1896, and that fact may be taken as an indication that no trouble has been caused by odor-producing organisms. Since the installation of the filter there has been an improvement in the odor of the water in the distributing reservoir The "mouldy" and "faint, musty" odors have, to a large extent, disappeared, and, at the present time, the water often has no odor.

It should be observed, however, that since the installation of the filter in 1893, the organisms have shown a slight tendency to increase (this is especially true in the case of *Crenothrix*), and, even if the figures are still too low to be of practical importance, it is to be hoped that in the interests of Science, the State Board of Health will continue to make these observations.

In reference to the bacteria in the filtered water, the authors mention the fact that the numbers in the distributing reservoir are often higher than those in the effluent after passing through the filter, or in the service taps in the city. They suggest as a reason that the increase may be due to bacteria entering the open reservoir from the air, or to the development of bacteria in the water. In the writer's opinion, these causes do not account for the large numbers often noticed, and he is inclined to the belief that the oftentimes excessively high numbers may be attributed to local contamination of the reservoir samples. The reports of the State Board of Health state that these samples are collected from a tap in the effluent gate-house. It may easily happen that, with a pipe used as little as this one undoubtedly is, abnormal results may be obtained. If this be the case, the bacterial results of the reservoir water are of little value, and the authors are justified in omitting the results from their table.

The general decrease in the number of bacteria in the pipes of the distributing system, and the occasional increase during the summer correspond with what has been observed elsewhere. Apparently, this summer increase is due to the growth and decay of organisms in the pipes.

Mr. Tribus. LOUIS L. TRIBUS, M. Am. Soc. C. E. (by letter).—Every few years the world takes up a new fad: sometimes useful; sometimes foolish. Some push it to the extreme, but, in time, the good in it becomes accepted and it reaches its true position in life's economy.

In sanitary science the ruling fad of the present is filtration, and it possesses so much of inherent merit as almost to justify the furor; still we do not need to run wild over it, or consider it as the universal panacea, as is a tendency to-day.

The past two decades have indeed marked wonderful advancement in the subject. At the beginning of that period, with a few exceptions, filtration meant only a straining out of suspended matters; nothing was thought of any organic purification.

Many were the filter tanks and hollow porous walls filled with sand, gravel or charcoal, used to strain out the vegetable growths and silt; becoming in themselves, because usually very improperly cared for, the breeding places for organisms more harmful than all the matters removed.

Occasionally, however, some systems did approximate to the more accepted forms of the present; the Poughkeepsie plant, designed by Mr. Kirkwood, being noteworthy; though its bacterial action was not considered at all as a factor, until probably after the Lawrence plant was inaugurated.

The chemist and the biologist have contributed a great deal of information as to Nature's method of action, and the public at large has even adopted and uses glibly, the terms "bacterial life," "nitrifying organisms," "colonies of germs," etc., as if it thoroughly understood the whole subject.

Many systems of treatment have been taken up, especially abroad, but they all gradually crystallize into the two, "slow" sand and "rapid" sand with chemical assistance; while results and efficiencies have been claimed at times scarcely within the realm of reason.

Still, great actual progress has been made, and greater intelligence is being daily brought to bear in the application of the principles concerned.

Percentages are dangerous forms of comparison, yet there seems to be no better method at times. In speaking of the removal of bacteria it may often be very misleading. For instance: 99 would seem to be a high figure, yet 99% removal from water carrying 5 000 bacteria per cubic centimeter gives no better result than 95% from water carrying 1 000 per cubic centimeter; in each case 50 per cubic centimeter remaining in the effluent.

The writer has no better method to propose, but simply calls attention to the danger of blindly specifying percentages, as is frequently done. Each case needs to be treated according to its own

Mr. Tribus. special local conditions and not by any general rule, which is very often particularly inapplicable.

The secret of success of any filter is not its percentage of bacterial removal, but, through careful operation, not alone careful design, the removal of all dangerous germs; this removal does not mean elimination of all bacteria, for many are entirely harmless to the human system, but the intelligent propagation of those which are harmless that shall aid in the destruction of those which are harmful.

It certainly is not taking too advanced a stand to say that every water that requires filtration to free it from polluting matters should be filtered under the constant care and daily examination of one trained in biological research as well as common sense.

In the discussion of this paper the decreased death list from typhoid is shown clearly, both at Lawrence and elsewhere, consequent on such installations, but, to demonstrate the point, we need not give all the credit to the engineer and the biologist.

When the fact became thoroughly demonstrated that typhoid was a filth-germ disease, cities began to cleanse the districts from which it was likely to emanate, and so lessened materially the numbers of cases. Then a far better comprehension of the disease itself brought more efficient treatment by physicians, thus cutting down the proportion of deaths to cases.

The same causes that induce a community to seek a purer water supply, if it be needed, are the ones that are effective from the sanitary and medical standpoints as well. The result attained is to be applauded, and filtration is justly entitled to a goodly share of the credit in the places where it has been established.

The financial value of the factor "saving of lives," because of improved municipal conditions, is not often appreciated.

Taking at Lawrence the average total deaths from typhoid for six years before and six years after the construction of the filter plant, as given in the paper, of 53 and 14 per year, respectively; cutting down the 53 average by one-third, to represent better medical and sanitary conditions, to say 35, compared with the 14, shows a saving of 21 lives per year at least, creditable to filtration of the supply; allowing $150 per year, as a low estimate of net gain to the community for each inhabitant; multiplying by the 21 equals $3 150, the net saving in the first year. In twenty years, a reasonable period to take for productive human life, the aggregate net earnings of the 21 persons saved each year, would, without any interest being added, equal $660 000, or an average of $33 000 per year that could be spent for interest, sinking fund and maintenance of the filter plant, without exceeding the real financial value of the service to the community; as against say $15 000 or $16 000 for the same items actually spent at Lawrence.

The 420 persons saved from death would also make an interesting exhibit. Mr. Tribus.

Did city officials, or the people as a whole, more generally understand and realize these facts, sanitation and purification would receive much more attention than has been or is even now being given to the case.

While endorsing, without any qualification, filtration of water supplies, whenever polluted, it would seem that there can be no question that, if a source of supply free from contaminating influences can be secured, such source is to be preferred in comparison even with the best methods of artificial purification possible; conditions of constructive and operative costs, permanence and accessibility for inspection being equal.

Bearing on that statement, in 1895 the State Board of Health of Massachusetts, reporting on a new supply for the Metropolitan District, after estimating that a filtered supply from the Merrimac River could be secured for less money (including operations, capitalized), than any other source considered, stated, that though it had been shown by the works at Lawrence (built from Mr. Mills' plans and described in the paper under discussion), that "waters as polluted as those of the Merrimac can be effectually filtered and rendered safe for domestic use," yet its conclusion was that "in the opinion of the Board it will be better to pay 10% more for a supply from a source that has not been polluted." Such a source was supposed to have been found.

It is not always possible for our cities to secure such uncontaminated supplies, even by those having large capital, and therefore ability, to go great distances; hence, the tremendous importance of filtration and its possibilities, and the great value of such conscientious investigation and pioneer construction, as described in this paper.

JOHN H. GREGORY, Assoc. M. Am. Soc. C. E. (by letter).—The authors are to be congratulated on presenting such a complete history of the construction and operation of the filter which has contributed so greatly to the advancement of water purification in this country. Various questions relating to the design and operation of the filter have been too ably discussed by others for the writer to add anything on these points, but a comparison of the costs of operation of the Lawrence filter with other filters may not be amiss. Such figures as are readily available have been compiled and are well worthy of careful study by those interested in the operation side of the question. Mr. Gregory.

In one of the tables presented by the authors, the total costs charged to various items are given. In order to reduce these to a basis for comparison with other plants, the figures have been worked over, using as a unit the cost per million gallons. The results are given in Table No. 36.

Mr. Gregory.

TABLE No. 36.—ITEMIZED STATEMENT OF COST OF OPERATION OF THE LAWRENCE FILTER, PER MILLION GALLONS, 1895–1900.

Items.	1895.	1896.	1897.	1898.	1899.	1900.
Scraping	$2.45	$1.23	$1.73	$1.60	$1.76	$1.76
Scraping and sanding		1.33	0.74	0.25	1.08	1.03
Conveying	1.27	1.07	1.94	1.37	1.26	1.16
Washing	0.96	1.92	1.72	1.32	1.24	1.25
Removal of snow and ice	2.68	2.14	2.06	2.87	1.97	1.93
General	0.43	0.45	0.75	0.59	0.43	0.60
Total	$7.79	$8.14	$8.96	$8.00	$7.74	$7.73
Total, minus snow and ice	5.11	6.00	6.90	5.13	5.77	5.80
Pumpage, million gallons	1 040	1 100	1 130	1 210	1 170	1 210

The average total cost of filtration for the six-year period was $8.05 per million gallons. The average cost of removing snow and ice for the same period was $2.27, and deducting this from the total cost leaves $5.78 as the average cost per million gallons, minus snow and ice.

In Table No. 36, the costs of superintendence and bills are charged to the various items. In order to separate these items, and thus obtain the cost of labor for the various operations, the authors have kindly furnished the writer with the figures for 1900, from which the following and other tables have been deduced.

TABLE No. 37.—ITEMIZED STATEMENT OF COST OF OPERATION OF THE LAWRENCE FILTER, PER MILLION GALLONS, FOR 1900.

Item.	Cost.	Percentage of cost.
Scraping (labor)	$1.50	19
Scraping and sanding (labor)	0.90	12
Conveying (labor)	1.02	13
Washing (labor)	0.94	12
Removal of snow and ice (labor)	1.56	20
General (labor)	0.38	5
Superintendence	0.91	12
Bills	0.52	7
Total	$7.73	100
Pumpage, million gallons	1 210	

In a paper recently read before the American Water-Works Association, the cost of operation of the Albany filters from July 26th, 1899, to December 29th, 1900, was given by Mr. George I. Bailey. The figures are presented in Table No. 38. In this table the cost of superintendence and supplies is charged to the various items, but the cost of maintaining the laboratory is not included.

Mr. Gregory.

TABLE No. 38.—ITEMIZED STATEMENT OF COST OF OPERATION OF THE ALBANY FILTERS, PER MILLION GALLONS, 1899–1900, 501 DAYS.

Item.	Cost.	Percentage of cost.
Scraping	$0.24	14
Wheeling out	0.45	27
Refilling	0.32	20
Incidentals	0.13	8
Lost time	0.10	6
Washing	0.42	25
Total	$1.66	100
Amount filtered, million gallons	6 463	

In order to make a comparison with the Lawrence figures for 1900, Table No. 37, in which the cost of labor is given, Mr. Bailey has kindly furnished the writer with figures from which Table No. 39 has been deduced.

TABLE No. 39.—ITEMIZED STATEMENT OF COST OF OPERATION OF THE ALBANY FILTERS, PER MILLION GALLONS, 1899–1900, 501 DAYS.

Item.	Cost.	Percentage of cost.
Scraping (labor)	$0.16	10
Wheeling out (labor)	0.30	18
Refilling (labor)	0.22	13
Washing (labor)	0.27	16
Incidentals (labor)	0.09	6
Lost time (labor)	0.07	4
Superintendence	0.33	20
Supplies	0.18	11
Wash water	0.04	2
Total	$1.66	100
Amount filtered, million gallons	6 463	

In comparing the labor costs at Lawrence and Albany, it should be stated that laborers are paid $2 for a day of 8 hours at Lawrence, and $1.50 for the same time at Albany.

The oldest filter plant in the United States, from which reliable figures are available, is at Poughkeepsie, N. Y. In Table No. 40 is given the cost of operating this plant from 1877 to 1900, a period of 24 years. These figures have been compiled from the annual reports of the Board of Water Commissioners of Poughkeepsie. The writer has endeavored, as far as possible, from the information given in the reports, to separate such costs as should be charged to construction, and to include in the table only those relating to operation. This is

Mr. Gregory.

TABLE No. 40.—ITEMIZED STATEMENT OF COST OF OPERATION OF

Items.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.
New sand	$0.13	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Cleaning	.....	.....	$0.98	$0.68	$0.75	$0.64	$1.17	$0.80	$0.45	$1.37	{ .....
Washing	1.46	.....	1.82	1.91	1.65	1.83	2.14	1.28	1.01	1.81[2]	{ $1.23[1]
Replacing	{ 0.65	{	.....	.....	.....	.....	.....	.....	.....	1.16	.....
Removing	{	{	.....	.....	.....	.....	.....	.....	.....	.....	.....
Removing ice	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Repairs	.....	.....	.....	.....	0.06	0.03	0.27	0.14	0.01	1.58[4]	.....
Operation (so-called)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Total	$2.24	$2.85	$2.80	$2.59	$2.46	$2.50	$3.58	$2.22	$1.47	$5.92	$1.23
Total, minus snow and ice	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Care of grounds	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Pumpage, million gallons	569	529	536	513	557	508	509	496	591	634	645

[1] Includes cost of removing ice.
[2] Old sand all removed and washed.
[3] Includes so-called cost of operation.
[4] Includes cost of construction of bridges.

stated here, inasmuch as the writer's figures may not agree exactly with those which others may have deduced. For example, Mr. Charles E. Fowler, Superintendent of the Poughkeepsie Water-Works, stated, in a paper read before the New England Water-Works Association in 1898, that the average cost of maintenance and operation, for a period of 20 years from 1877 to 1896, inclusive, was $2.99 per million gallons. The figure as deduced by the writer for the same period would be $2.92 per million gallons, the difference between the two being due, as stated above, to the charging of certain costs to construction.

The average total cost of operation at Poughkeepsie for the period covered by Table No. 40, 1877 to 1900, inclusive, has been $3.27 per million gallons. During the last three years only, 1898 to 1900, inclusive, has the cost of removing snow and ice been reported separately. This cost has averaged $0.47 per million gallons, and deducting this from the total average cost, $2.42, for the same period, leaves $1.95 as the cost per million gallons minus snow and ice.

In a recent number of *Engineering News* was published the cost of operating the filters at Mt. Vernon, N. Y. These figures have been reduced to the basis of cost per million gallons, and are given in Table No. 41.

The average total cost of filtration for the six years, 1895 to 1900, inclusive, has been $3.16 per million gallons. For the last five years, 1896 to 1900, inclusive, the average total cost has been $3.33 per million gallons, and deducting from this the average cost of removing snow and ice for the same period, $0.35, leaves $2.98 as the average cost per million gallons, minus snow and ice.

THE POUGHKEEPSIE FILTERS, PER MILLION GALLONS, 1877–1900. Mr. Gregory.

1888.	1889.	1890.	1891.	1892.	1893.	1894.	1895.	1896.[6]	1897.	1898.	1899.	1900.
.....	.....	.....	.....	$1.21		.....	.....	.....	$5.63	.....	.....	.....
1.33[1]	1.76[1]	.....	1.40[2]	1.81	3.46	2.50[3]	$2.88[3]	$1.05	0.67	$1.19	$1.03	$1.31
.....	.....	1.86	.....	.....	0.93	0.37	0.46	.....	.....	0.85	0.56	0.82
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
0.14	0.31	0.38	0.04	0.40[5]	0.14	0.11	0.22	.....	6.42[6]	0.48	0.36	0.60
.....	.....	1.76	.....	.....	.....	.....	.....	3.22	.....	.....	.....	0.12[9]
$1.47	$2.07	$4.00	$1.44	$3.42	$4.53	$2.98	$3.56	$4.27	$12.72	$2.52	$1.95	$2.85
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	$2.04	$1.59	$2.25
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	$1.55	$1.34	$1.47
609	572	603	628	696	667	634[7]	687[7]	664[7]	615	611	717	653

[5] Includes cost of new sand washer.
[6] Repairs to old bed and inlet basin, and removal and wasting of old sand.
[7] Exclusive of leakage.
[8] Cost of tools only.
[9] New bed built, and put in operation December 17th, 1896.

TABLE No. 41.—ITEMIZED STATEMENT OF COST OF OPERATION OF MT. VERNON FILTERS, PER MILLION GALLONS, 1895–1900.

Items.	1895.	1896.	1897.	1898.	1899.	1900.
Cleaning and renewing beds	$1.99	$1.90	.....	.....	.....	$1.32
Cleaning beds	.....	.....	$1.35	$1.85	.....	.....
Overhauling sand bed	.....	.....	.....	.....	.....	1.43
Cost of new sand	.....	.....	.....	.....	.....	0.24
Washing sand	.....	.....	0.50	0.50	.....	0.75
Placing sand on beds	.....	.....	0.52	0.49	.....	.....
Removing ice	.....	0.03	0.21	0.42	$0.81*	0.21
Miscellaneous	0.02	0.06	0.05	0.04	.....	0.10
Total	$2.01	$1.99	$2.63	$3.30	$4.45	$4.05
Total, minus removing ice	.....	1.96	2.42	2.88	3.64	3.84
Consumption—Million gallons	493	608	646	686	726	679

* Only one item reported.

For comparing conveniently the average cost of operating the four plants, Table No. 42 has been compiled.

Passing now from a study of the cost of operation to a study of the work in detail, some very interesting figures relating to the Albany and Lawrence plants can be deduced. The figures from which the deductions of the Albany plant have been made, are taken from Mr. Bailey's paper, and the writer, being well acquainted with the conditions at Albany, has made an analysis of these figures, the results of which are given in Tables Nos. 43 to 46.

Mr. Gregory.

TABLE No. 42.—COMPARISON OF COST PER MILLION GALLONS OF OPERATION OF FILTERS AT LAWRENCE, ALBANY, POUGHKEEPSIE AND MT. VERNON.

	LAWRENCE	ALBANY.	POUGHKEEPSIE.		MT. VERNON.	
	1895–1900, 6 years.	1899–1900, 501 days.	1877–1900, 24 years.	1898–1900, 3 years.	1895–1900, 6 years.	1896–1900, 5 years.
Average total cost	$8.05	$1.66	$3.27	$2.42	$3.16	$3.33
Average cost of removing snow and ice	2.27	.....	.....	0.47	.....	0.35
Average cost, minus snow and ice	5.78	.....	.....	1.95	.....	2.98

TABLE No. 43.—DETAILED STATEMENT OF SCRAPING OF THE ALBANY FILTERS, 1899–1900, 501 DAYS.

	Hours of labor.	Cubic yards.	Barrows.	Cost of labor.
Total	5 481	7 942	100 145	$1 047.35
Per bed (0.7 acre, approx.)	43.2	62.5	789	8.25
" acre	61.4	*89.0	1 121	11.73
" 1 000 sq. ft.	†1.41	2.04	25.8	0.27
" cubic yard	0.69	.....	12.6	0.13
" hour of labor	.....	1.45	18.3	.....
" 8 hours of labor	.....	11.6	146	.....
" million gallons filtered	.....	1.23	155	0.16

* Average thickness removed, 0.66 in. = $\frac{11}{16}$ in. = 0.055 ft. approximately.

† 1.41 hours per 1 000 sq. ft. = 710 sq. ft. per hour = 11.8 sq. ft. per minute = 5 680 sq. ft. per 8 hours.

Scraping includes the removal of covers from the ventilator shafts in the vaulting, and the scraping into piles of the dirty sand from the surface of the bed.

TABLE No. 44.—DETAILED STATEMENT OF WHEELING OUT AT THE ALBANY FILTERS, 1899–1900, 501 DAYS.

	Hours of labor.	Cubic yards.	Barrows.	Cost of labor.
Total	10 238	7 942	100 145	$1 956.88
Per bed (0.7 acre, approx.)	80.6	62.5	789	15.41
" acre	115	89.0	1 121	21.92
" 1 000 sq. ft.	2.64	2.04	25.8	0.50
" cubic yard	1.29	.....	12.6	0.25
" hour of labor	.....	0.77	9.8	.....
" 8 hours of labor	.....	6.2	78	.....
" million gallons filtered	.....	1.23	15.5	0.30

Mr. Gregory

Wheeling out includes the handling of the running plank, shoveling the scraped material into wheel-barrows and removing it to the court, raking and screeding the bed, and replacing the covers on the ventilator shafts. The average round trip distance for removing the sand is about 500 ft.

During the last five months that the writer was connected with the construction of the Albany plant, the filters were put in operation one after another, as soon as completed, and the opportunity was afforded of keeping a force account of all the operations. Mr. Bailey's figures cover all those obtained by the writer, but in those of Mr. Bailey the cost of raking and screeding the surface of the sand just prior to refilling and starting a run is included in the cost of wheeling out. For a portion of the time the writer kept these figures separately, and, as they are of interest, they are given in Table No. 45.

TABLE No. 45.—Detailed Statement of Raking and Screeding the Albany Filters, 1899.

Hours of labor per bed (0.7 acre, approx.)	22.6
" " " " acre	32.2
" " " " 1 000 sq. ft	9.74
Square feet per minute of labor	22 5
" " " hour of labor	1 352
" " " 8 hours of labor	10 810
Cost of labor per bed	$4.25
" " " " acre	6.05
" " " " 1 000 sq. ft	0.14

In Tables Nos. 43 and 44 the details of scraping and wheeling out at the Albany filters have been given separately. In order to compare the relative rates of work at Albany and Lawrence, these two tables have been combined in one, Table No. 46, covering what may be called cleaning the filters, and including all the operations mentioned under the heads of scraping and wheeling out.

TABLE No. 46.—Detailed Statement of Cleaning (Scraping and Wheeling out) of the Albany Filters, 1899–1900, 501 Days.

	Hours of labor.	Cubic yards.	Barrows.	Cost of labor.
Total	15 719	7 942	100 145	$3 004.23
Per bed (0.7 acre, approx.)	124	62.5	789	23.66
" acre	176	89.0	1 121	33.65
" 1 000 sq. ft	*4.05	2.04	25.8	0.77
" cubic yard	1.98	.....	12.6	0.38
" hour of labor	.....	0.50	6.4	.....
" 8 hours of labor	.....	4.0	51	.....
" million gallons filtered	.....	1.23	15.5	0.46

* 4.05 hours per 1 000 sq. ft. = 247 sq. ft. per hour = 4.1 sq. ft. per minute = 1 980 sq. ft. per 8 hours.

Mr. Gregory. The process of scraping at Lawrence includes, as the authors state, the scraping up of the dirty sand, its removal to the bank by wheel-barrows, and the raking and screeding of the bed. It will be seen that this compares very closely with what the writer has called cleaning at Albany, as the distance the dirty sand is wheeled is about the same at each place. The figures for 1900 at Lawrence are given in Table No. 47.

TABLE No. 47.—Detailed Statement of Scraping of the Lawrence Filter, 1900.

	Hours of labor.	Cubic yards.	Cost of labor.
Total	8 296	2 350	$1 820.00
Per acre	228	*64.7	50.08
" 1 000 sq. ft.	†5.25	1.49	1.15
" cubic yard	3.53	.....	0.77
" hour of labor	.....	0.28	.....
" 8 hours of labor	.....	2.26	.....
" million gallons filtered	.....	1.94	1.50

*Average thickness removed, 0.48 in. = 1/25 in. = 0.04 ft.
†5.25 hours per 1 000 sq. ft. = 191 sq. ft. per hour = 3.2 sq. ft. per minute = 1 524 sq. ft. per 8 hours.

TABLE No. 48.—Comparative Statement of Cleaning Filters at Lawrence, Albany and Poughkeepsie.

	Lawrence.	Albany.	Poughkeepsie.	
	1900.	1899-1900.	Without bridges.	With bridges.
Hours of labor per acre	228	176	290	181
" " " " 1 000 sq. ft.	5.25	4.05	6.66	4.17
" " " " cubic yard	3.53	1.98	.....	.....
Square feet per hour of labor	191	247	150	240
" " " " minute of labor	3.2	4.1	2.5	4
" " " " 8 hours of labor	1 524	1 980	1 200	1 920
Cost of labor per acre	$50.08	$33.65	.....	.....
" " " " 1 000 sq. ft.	1.15	0.77	.....	.....
" " " " cubic yard	0.77	0.38	.....	.....
" " " " million gallons	1.50	0.46	.....	.....

At Poughkeepsie, prior to 1886, and again since 1897, the filters have been cleaned by the same method as that used at Lawrence and Albany. Mr. Fowler stated that the labor required under normal conditions, was one man for each 150 sq. ft. of surface cleaned per hour, including wheeling and elevating to the bank. In 1886 two bridges were constructed, spanning the two sections of the bed. These bridges were movable, and, from them, platforms were suspended a little above the surface of the sand. The men stood upon these platforms and scraped up the dirty sand, throwing it on the plat-

forms. When a portion of the bed had been cleaned, the bridges were moved to one end of the bed and the sand was thrown up on the bank. By this process, under normal conditions, one man would clean 240 sq. ft. of surface per hour. The cost of labor at Poughkeepsie was not given, but these figures, with others derived from them, are compared in Table No. 48 with corresponding ones at Lawrence and Albany. Mr. Gregory.

In Tables Nos. 49 and 50 will be found the details of the sand-washing operations at Lawrence and Albany.

TABLE No. 49.—Detailed Statement of Washing Sand at the Lawrence Filter in 1900.

	Hours of labor.	Cubic yards.	Cost of labor.
Total	5 152	3 000	$1 130.00
Per cubic yard	1.72	.....	0.38
" hour of labor	.....	0.58	.....
" 8 hours of labor	.....	4.66	.....
" million gallons filtered	.....	.....	0.94
* Wash water per cubic yard of sand	.....	.....	.....

* Wash water, 10 volumes of water per volume of sand = 270 cu. ft., or 2 020 galls. of water per cubic yard of sand.

TABLE No. 50.—Detailed Statement of Washing Sand at the Albany Filters, 1899–1900, 501 Days.

	Hours of labor.	Cubic yards.	Barrows.	Cost of labor.
Total	8 923	5 673	83 299	$1 706.25
Per cubic yard	1.57	.....	14.7	0.30
" hour of labor	.....	0.64	9.3	.....
" 8 hours of labor	.....	5.1	75	.....
" million gallons filtered	.....	.....	.....	0.27
* Wash water per cubic yard of sand	.....	.....	.....	0.04

* Wash water, 12½ volumes of water per volume of sand = 337.5 cu. ft. or 2 525 galls. of water per cubic yard of sand.

At Lawrence, washing includes the screening of the dirty sand at the first or traveling hopper of the washer and the transportation from the draining boxes to the permanent storage bank, together with such attention as the washer itself requires.

At Albany, washing includes the handling of scraped sand from the storage piles to the sand washer, attendance on the sand washer and removing the washed sand to a storage pile.

At both places the ejector type of machine is used, the nozzles at Lawrence being horizontal, while those at Albany are vertical.

Mr. Gregory.

The processes of sanding at Lawrence, and of refilling sand at Albany are nearly the same. The authors state that sanding includes removing the clean sand from the storage bank to the surface of the bed, distributing it in layers and smoothing the surface, also the labor necessary to prepare the surface of the bed for this operation. At Albany, refilling includes removal of washed sand from storage piles into the filter, loosening the top layer of the sand about 6 ins. deep and leveling the new sand.

The work at both places would be directly comparable but for the fact that the Lawrence figures include one scraping of the surface just prior to sanding. As the labor for this is but a small portion of the total charged to sanding, the writer believes that the figures for Lawrence in 1900, given in Table No. 51, are fairly comparable with those for Albany given in Table No. 52.

TABLE No. 51.—Detailed Statement of Scraping and Sand of the Lawrence Filter in 1900.

	Hours of labor.	Cubic yards.	Cost of labor.
Total	5 000	3 400	$1 090.00
Per cubic yard	1.47	.....	0.32
" hour of labor	.....	0.68	.....
" 8 hours of labor	.....	5.44	.....
" million gallons filtered	.....	.....	0.90

TABLE No. 52.—Detailed Statement of Refilling Sand at the Albany Filters, 1899–1900, 501 Days.

	Hours of labor.	Cubic yards.	Barrows.	Cost of labor.
Total	7 437	5 673	89 081	$1 421.15
Per cubic yard	1.31	.....	15.7	0.25
" hour of labor	.....	0.76	12.0	.....
" 8 hours of labor	.....	6.1	96	.....
" million gallons filtered	.....	.....	.....	0.22

Although the cost of operation at Lawrence has been high, it should be remembered that the filter is an uncovered one, that it is in a climate subject at times to severely cold weather, and that it has been operated under rather disadvantageous conditions. But in spite of all this the money has been well spent, and the good work accomplished by it has been recognized by engineers, and is fast being recognized by the public at large.

Mr. Fowler. CHARLES E. FOWLER, Esq.* (by letter).—In the writer's experience with the open filters at Poughkeepsie, covering a period of twenty years, he has not observed that the delivery of the filters, immediately after scraping, was in any wise affected by air entrained in the sand, although it was the invariable practice, until within a few years, to fill the filters by flowing the water over the sand.

The manipulation of the filter prior to and during scraping, however, will affect the immediate delivery very materially. In fact, the writer has known a scraping to be performed in such manner and under such conditions as to absolutely stop the flow, and the operation had to be repeated, in different manner and under different conditions, before any water could be coaxed through. Undue pressure or head, habitually or frequently carried, has a strong tendency to produce the result mentioned. The practice of forking or deep raking also tends in the same direction. With these prior conditions and the bed a little too moist it will require but a small amount of inattention on the part of the person in charge, and improper handling of the shovels by the scrapers, to effect a very material reduction in the delivery immediately after scraping. If the bed is in good order, the immediate delivery may be varied by the depth of sand removed in scraping, even when the filling is from below.

The maximum head allowed on the Poughkeepsie beds, during recent years, is 4 ft. Sometimes they are scraped when the head is less, depending upon the rate of increase of head and the condition of the applied water. Ordinarily, the head immediately after scraping is less than 1 ft.

It became necessary to scrape the beds in April, last, when the applied water was in an unusually turbid condition. The head before scraping was 3.2 ft. Intentionally, less than the usual depth of sand was removed, and the head on starting up was 2.0 ft., the beds being filled from below. The chief object in filling these beds from below is to avoid furrowing the sand by the inflowing water.

In scraping the Poughkeepsie beds, the sand is not first placed in heaps, as described and illustrated in the paper, but, when lifted from the surface by the shovels, it is deposited in barrows. Sandals are not used. In smoothing the surface of the sand, after scraping, the back of a rake only is used. Even the shortest teeth are not used, the endeavor being to cause as little disturbance of the sand surface as possible. Shovels are not allowed to be stuck vertically in the sand.

The minimum cost of scraping is about $46 per acre, or 0.12 cent per square foot. The men employed are picked up for the occasion, and are such as do not readily find employment elsewhere. They are about the lowest grade of laborers. The minimum number employed is 23, and they occupy 2 days, of 8 hours each, in scraping $1\frac{1}{3}$ acres.

* Superintendent and Engineer of Public Works, Poughkeepsie, N. Y.

Mr. Fowler. Each man receives $1.50 per day. The walls of the basins are vertical, and the top of the coping is about 6 ft. above the sand surface. The cost of scraping given above includes depositing in barrows, wheeling to the corners of basins, throwing up to top of coping and trimming back on pile. Two laborers are employed about the beds and grounds, but are not used in scraping. During the intervals between scrapings these men wheel to the storage pile the sand thrown up from the filters.

It was formerly the practice to wash the scraped sand and store it for replacing; the washing being done by 2 to 4 men through the spring, summer and fall months. It is the present practice to store the sand unwashed, during the year, and when the time for replacing arrives, usually in October, the sand is washed and replaced on the beds as washed. A much greater number of men is employed, and the operation requires about 16 days to wash and replace one year's scrapings on an area of $1\frac{1}{3}$ acres. The sand is thrown into a hopper at the storage pile and forced by a water-jet to a series of inclined troughs discharging into a tank from which the silt and dirty water overflows, and a water-jet at the bottom forces the sand through a pipe to a tank set over one edge of a bed, the water flowing off at the top and the sand discharging in a pile on the surface of the bed.

The sand is distributed over the bed by barrows. There is no carting, and the only wheeling is on the bed. In 1900 the cost of labor for washing sand was 32.2 cents per cubic yard. The cost of labor for washing and replacing was 58.4 cents per cubic yard. The total quantity washed and replaced was 910 cu. yds. The average quantity per hour was 6.78 cu. yds., and per day, 54.3 cu. yds. All the quantities given are for clean sand measured on the bed. The pay of the laborers was $1.50 per day of 8 hours.

The yearly cost of ice removal varies with the thickness of the ice, the number of times taken off, distance to be removed, etc. For the three years prior to 1900–01 the cost varied from $146.61 to $440.49; average, $281.01. In 1900–01 the ice was taken off only once, and the cost was $613. The ice was much thicker than usual, averaging $13\frac{1}{2}$ ins. on the old bed and 18 ins. on the new bed, each bed being $\frac{2}{3}$ acre in area. The distance to which the greater portion of the ice was removed was also materially greater. The work was done entirely by manual labor, and occupied 62 hours. The minimum number of men employed was 54 and the maximum 64. The rate of pay was $1.50 for 8 hours. The men comprised all kinds of laborers who chanced to be in want of employment.

The ice was sawed in one direction and broken by chisels in the other. The cakes were floated to a run at the side of the basin, and pulled up by men with pikes. The surface of the water was maintained as near the coping as practicable, generally less than 1 ft below

the top. After the cakes were lifted out they were pushed on nearly horizontal runs to the place of deposit. This is the most costly part of the operation. The cost of cutting and lifting the ice out of the basins was $289.32 for the entire area, or $192.88 per acre. The total cost per acre of filtering area was $408.66. The total cost per million gallons filtered was 94 cents. There is no removal of snow other than with the ice. The ice covering the beds is not allowed to touch the sand at any time if it can be avoided. Mr. Fowler.

WILLIAM B. FULLER, M. Am. Soc. C. E. (by letter).—Thanks are due to the authors for their painstaking labor in compiling and making available these data concerning the Lawrence filter; for it is by a study of such data from existing plants that we can hope to improve the efficiency of and decrease the expenditures on future works of this kind. Mr. W. B. Fuller.

In applying the experience gained at Lawrence to other places, it must be borne in mind, however, that the conditions there are not such as are likely to occur at many other localities; two factors, especially, contributing to this result, namely, the extreme pollution of the river and the small amount of turbidity. Both of these factors are very favorable to high efficiency in slow sand filtration, and undoubtedly account for the favorable showing made by the plant, which in so many particulars contains features which are now avoided.

From the writer's point of view, the great value of this paper lies in the presentation of the detailed costs of operation and the consequent bringing out, in discussion, of the comparative costs of operation at other works. It is shown that a large percentage of this cost is due to the removal of the dirty sand from the beds, its transportation outside, washing, storing and transportation back again, and a study of these costs shows two matters which should receive serious attention in the design of new plants:

First: The keeping of the amount of sand handled per million gallons at its lowest point consistent with efficiency, and

Second: The reduction in cost of handling the sand by the substitution of machinery for hand labor.

In relation to the reduction in thickness of the sand layer to be removed, Mr. George W. Fuller suggests the clogging caused by entrained air as a serious factor affecting the quantity of sand handled, and Mr. Collins suggests, among others, rain, snow, ice, freezing of the exposed sand, and unskilled labor. The troubles due to entrained air are now generally recognized and avoided by the use of methods of refilling from below and by the use of positive heads during operation. Most of the troubles suggested by Mr. Collins can be avoided by covering the filter beds, thus adding new reasons to the already long list in favor of covered filters.

Mr. W. B. Fuller.

In relation to the reduction of cost in handling the sand it appears that the methods now in vogue are costly and cumbersome; they are methods copied from the operation of the older plants of England and Germany, scraping by hand labor, transportation by wheel-barrows or carts, and washing and storing involving much hand labor, but it would seem that such methods are hardly adapted to this country with its higher-priced labor.

The space set apart for the storage of sand is also an important element in the first cost of the plant, and one which it would be desirable to eliminate.

For several years the writer has been of the opinion that the principle of water transportation, greatly extending the idea described by the authors for the transportation of sand to the sand-washer, will materially reduce such costs.

He would suggest the use of many stationary hoppers situated in different portions of a filter bed with the necessary piping leading to a central sand washer, and a transportation pipe from the last sand washer to the place of storage.

He would also suggest that the units of a filter plant be made of such small size as would permit of two units being out of commission at one time. The dirty sand would then be removed from one unit, transported to the sand washer, washed and transported to place in the other unit without the intervention of unsightly storage heaps or costly storage courts, and with a minimum of hand labor. Further, it would be advisable to use covered filters well lighted by artificial light to allow of continuous work in stormy, dark or freezing weather, thus insuring the employment of a permanent trained force, working under uniform conditions, during the entire year, a result which, in itself, as pointed out by Mr. Collins and Mr. Bailey, would insure a maximum of efficiency in such labor.

A point worth noting in relation to the removal of ice at Lawrence is, that owing to the large size of the unit the ice could be floated from one side to another without removal for several scrapings. If the filter plant had been divided into smaller units, this could not have been done, and the resultant cost of removing ice would have been greater.

Messrs. Knowles and Hyde.

Morris Knowles, Assoc. M. Am. Soc. C. E., and Charles G. Hyde, C. E. (by letter).—The writers are in no small measure gratified by the response with which the publication of their paper on the Lawrence, Mass., city filter has been met. They feel that the nature and scope of the discussions have been such that the paper has been given a value which it would otherwise have lacked. This is due not only to the extended reference to the general principles involved in filtration, and to the salient features of the design and operation of the particular filter in question, and of other works, but also to the careful

and elaborate statements and tabulations of cost which appear in several discussions. Messrs. Knowles and Hyde.

In the sections which follow, the writers have made such additional or explanatory statements as will serve to complete the information relative to the filter, where the discussions have shown the data in the original paper to be meager; and have suggested answers to the important questions which have been presented.

Water-Shed Populations.

A recomputation of the total population resident in 1900 upon the water-shed of the Merrimac River above Lawrence has been made upon a different basis from that used in producing the figure originally presented by the writers. The revised estimate of 480 000 persons agrees very closely with that of Mr. Hazen on page 309. The figure for urban population deduced by the writers, however, differs from that of Mr. Hazen on account of the assumption, in the first case, of 5 000 as a limit of rural population in a township, while Mr. Hazen's estimate is based upon a limiting rural population of 4 000.

The writers are glad to have the correct estimate of the total water-shed population of the Hudson River above Albany, and have included the changed figure in Table No. 3. But they would, at the same time, call attention to the fact that if the rural population of 1890 be added to the urban of 1900,* a total of 89 per square mile is obtained. This means, as compared with Mr. Hazen's new figures, an apparent reduction of 30% in rural population in ten years; in fact, however, the decrease is not as great; for the upper limit of rural population, in the table used as a basis by the writers, is 1 000, while, for the statement on page 312, Mr. Hazen has used 4 000 as the limit.

Construction.

The suggestions of Mr. Collins, in that part of his discussion entitled, "Conditions Due to the Construction of the Filter in One Unit," relative to the erection of division walls across the filter, appear to be most pertinent. If this feature were introduced, there is little doubt that the work of maintenance would be rendered more satisfactory in many ways, and much more economical.

Investigations in Regard to Clogging, and Work of Renewal, of Underdrains.

Since the presentation of the paper, the writers have had opportunity to finish the compilation of the necessary data, and to prepare a comprehensive statement regarding the conditions which led to the repair work during the years 1898 and 1900, together with some refer-

* *Transactions*, Am. Soc. C. E., Vol. xliii, p. 284.

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ence to the results obtained. Allusions to these matters have already been made in several discussions on the paper, and the information contained in these and in the following statements will, it is believed, answer Mr. Soper's inquiries and Mr. Weston's question.

Conditions for a Few Years after Construction of Filter.—For two years following the construction of the Lawrence filters, no serious difficulty was found, for any continued interval of time, in obtaining from it a supply of water entirely adequate for the demands of the city, without the necessity of operating the pumps for more than about two-thirds of the day, nor during Sundays and holidays, and without producing an excessive loss of head. Especially during the warmer portions of the year, the filter was found to work admirably, although the average loss of head under ordinary working conditions was always, after a while, greater than in the beginning.

The circumstances of operation and of scraping during the coldest weather, however, were unsatisfactory, owing to the lack of a cover over the filter. On the water surface thick layers of ice would form, which, when the filter was drained for scraping, lowered with the water down to the sand, thus disturbing the *schmutzdecke*. When the water rose again on the filter, portions of the sand were brought up with the ice, leaving the surface raw and broken, sometimes to a considerable depth. In addition, the freezing of the sand surface wherever it was exposed for scraping, the necessity for scraping quickly (which, unfortunately, led to the practice of scraping only those beds nearest the pumping station, and of allowing those further away to remain uncleaned for long periods during the winter), together with the lower temperature of the water, all combined to gradually increase the loss of head. The serious effects produced by this state of affairs obtained throughout all seasons, but especially during the cold weather, to such an extent that, to force the required amount of water through the filter, the water in the pump-well was drawn down to a level below the point of discharge of the underdrains of the beds, thus allowing air to pass through them back into the filter

Later, the filter appeared to be clogging elsewhere than at the surface, until, to some extent during the cold weather of 1895–96, and to a greater degree during the winter of 1896–97, it was found that the usual quantity of water could not be obtained from the filter, even with the maximum possible loss of head; consequently, the rate was diminished and the hours of pumping increased. During the winter of 1897–98, these conditions became greatly aggravated, and, in February of the latter year, the pumps were run day and night, with interruptions only to allow the water to rise in the pump-well to a sufficient height to provide water for the pumps. The loss of head was constantly equal to the maximum difference in elevation between the water on the surface and the bottom of the underdrains, while

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the surface of the water in the conduit was often much lower than the latter. Notwithstanding the continuous pumping, which oftentimes could not be carried on at a speed greater than two-thirds of the customary rate, the water in the reservoir, the capacity of which was equivalent to about two weeks' supply for the city, continued to lower, until half the storage was exhausted, and a partial water famine became imminent. Scraping the beds (which in the very coldest weather was almost impossible) appeared to produce but little benefit, and the conditions were such as to lead to grave apprehension on the part of the Water Board. The advent of warmer weather in March, 1898, however, permitted filtration to be carried on under somewhat more favorable circumstances, and the reservoir was gradually filled during the following month.

TABLE No. 53.—EXPERIMENTS TO DETERMINE THE VERTICAL DISTRIBUTION OF THE LOSS OF HEAD, INDICATING LOCATION OF CLOGGING IN LAWRENCE FILTER.

Depth of bottom of tube below surface of sand.	Position of sand layer relative to surface.	February 26th, 1898.			March 17th, 18th, 1898.		
		Percentage of Loss of Head.					
		Bed No. 5.	Bed No. 11.	Bed No. 21.	Bed No. 5.	Bed No. 11.	Bed No. 21.
8 ins.....	0 in.— 8 ins.	6	7	10	16	16	12
18 "	8 " —18 "	94	14	10	84	13	15
36 "	18 " —36 "	0	43	10	0	28	2
52 "	36 " to top of underdrains.	0	36	70	0	32	18
In gravel.....	Underdrains.				0	11	53
		100	100	100	100	100	100

Investigations of the Lawrence Water Board.—The serious aspect of the problem confronting the Water Board, of which, one of the writers, Mr. Knowles, was a member, led to the undertaking of a series of experiments to ascertain the relative extent of the clogging in different portions of the filter area, and the head required to force water through successive layers of the main body of the sand of the filter at these places. For this purpose there were used tubes of various lengths, having an interior diameter of about 3 ins. These were constructed of galvanized sheet-iron with conical bottoms, which were perforated with small holes and provided with a fine screen of brass wire at the junction of the base of the cone with the tube, in

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order to prevent the entrance of sand.* The tubes were set into the sand, over the southerly ends of the pipe underdrains, of Beds Nos. 5, 11 and 21, with the tops somewhat above the elevation of the surface of the water on the filter.

When the filter was in operation and the pumps were running, observations of the relative elevation of the surface of the water in the tubes and on the filter indicated the loss of head at various depths. On February 26th, a series of measurements was made with tubes placed in each bed to depths of 8, 18 and 36 ins. below the surface of the sand, and, on March 17th and 18th, the experiment was repeated with the addition of a fourth tube, the bottom of which rested directly on the top of the gravel underdrains, at an average depth of 52 ins. below the sand surface. On February 26th the observations were taken half-hourly, through an interval of 3 hours, and, on March 17th and 18th, taken hourly, through intervals of 7 and 8 hours, the fluctuation in the elevation of the water of the tubes being inconsiderable at all times. The results of these experiments are shown in Table No. 53.

During the experiments there was constantly maintained a total loss of head of 7 ft., which is the maximum obtainable with the surface of the water on the filter at its usual elevation. It will be seen that the loss of head in the upper sand layer was apparently, in all cases, a comparatively small percentage of the total, but it is possible that these results were vitiated by the fact that the tubes, being set into the sand to a depth of 8 ins. only, allowed the water on the filter, under a head of somewhat more than 3 ft., to force itself downward along their sides and up through the perforated conical bottoms, thus giving an apparent loss of head much less than the actual.

In Bed No. 5, near the pumping station, the entire loss of head was found to occur, during both series of observations, within the upper 18 ins. of the sand layer. In Bed No. 11, 21 to 29% of the total head was lost in the upper 18 ins., and the entire head was used up in passing through the main body of sand, the loss in the underdrains being inappreciable. In Bed No. 21, representing the easterly portion of the filter, farthest from the pumping station, where subsequent excavation proved the underdrain material to be badly clogged, the experiments showed that the loss of head in the upper 18 ins. of the main sand body was from 20 to 27% of the total, and that in the lower 16 ins. and underdrains was about 70%, of which the more comprehensive experiments of March 17th and 18th indicated that 53% was lost in the gravel underdrains alone.

The results of these studies indicated that there was a portion of the filter which contributed but little to the water supply for the city.

* Similarly constructed tubes have been used by the writers with gratifying success upon other work, and there is no doubt of their value as instruments to ascertain the variations in rates of filtration in different parts, and the loss of head through different depths of a filter.

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It was thought best, however, before doing anything further, to consult the State Board of Health, under whose advice the filter was built.

Application of Lawrence Water Board to Massachusetts State Board of Health for Advice; and the Reply.—At a meeting of the Lawrence Water Board, held March 4th, 1898, it was voted to address the following letter to the State Board of Health:

"The Lawrence Water Board respectfully represents that the municipal filter does not furnish sufficient water for the demands upon our system. We are led to believe, from limited experiments showing the loss of head, that portions of the filter are clogged.

"We desire to be advised by your Board in regard to the proper method to be adopted to restore the filter to its proper capacity, also to co-operate with us and advise what further experiments may be necessary to determine what portions need to be renewed."

In response to this request, the engineers of the State Board of Health made, during the following summer, an examination of the condition of the filter, and an investigation of the methods of manipulation and maintenance since its construction. By means of properly distributed tubes, sunk to various depths in the sand of many of the beds, the rate of draining of these beds was ascertained when the water was below the surface. Current meter observations were made of the rate of flow from the underdrain of each of the beds discharging directly into the old filter gallery and of the total flow from those discharging into the conduit. In several beds in the easterly portions of the filter, where tube measurements indicated a subsurface clogging, excavation was made to examine the lower sand layers and the condition of the underdrain material, principally in the vicinity of the underdrain pipes and the main conduit.

As a result of these studies, on September 19th, 1898, the State Board of Health sent the following reply to the Lawrence Water Board, in regard to the general condition of the filter and the method by which it might be improved:

"The State Board of Health received from you, on March 5th, 1898, the following request for advice with reference to improving the capacity of the Lawrence City Filter. * * *

"The Board has examined the available data as to the operation and management of the filter and the consumption of water as furnished from the records kept by your Board, and has made investigations to determine the quality and condition of the sand in the filter, and the condition of the underdrains as compared with their condition when first placed in the filter five years ago. The Board has also made many experiments to determine the cause of the reduced capacity of the filter and the best method of relief.

"Analyses of many samples of sand collected from all parts of the filter show that, while the effective size of the sand is probably slightly finer than when first placed in the filter, on account of silt carried by the river water, the increase in the fineness of the sand is not sufficient to cause a very material reduction in the quantity of water that would pass through the filter.

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"A careful examination of the height of water in the sand of the filter while it was being drained showed that, while the portion nearest the pumping station, amounting to approximately half the area, for the most part drained down rapidly, the water in the easterly half of the filter did not drain down readily, and in some portions of it remained, after several hours of draining, but little below the surface of the sand.

"Excavations were made through the whole depth of the sand and into the gravel forming and surrounding the underdrains. The sand was found to be clean and unobstructed throughout its full depth, and in the portion of the filter near the pumping station the gravel under the sand was found where examined to be in good condition, and the water appeared to drain freely through it. More attention was given to the easterly portion of the filter, where, as has been stated, the water did not drain readily from it. Here, as elsewhere, the sand was found in nearly all parts of it to be clean and unobstructed down to the gravel; but within the gravel and between the stones surrounding the drain pipes and in the joints of the drain pipes was found a deposit of gelatinous iron rust, together with some *Crenothrix*, a plant which grows in water containing iron, which deposit allowed very little water to enter the drain pipes. This deposit was more dense in the middle and upper portion of the layer of gravel, where air has entered this layer from the underdrains when the water in the pump-well has been drawn below the top of the underdrains.

"It is evident from the character of this deposit that air is essential to its formation; and the only way to prevent its formation in the future is to run the filter, as it was intended to be run from the time of construction, with the water in the pump-well always above the top of the underdrain, or not below the level of 31 ft. on the scale of heights.

"This portion of the filter can be rendered efficient by excavating trenches 10 ft. wide across the filter, in line of and over the underdrains, removing the gravel for this width, washing and relaying the pipes, and at the same time extending the lines of 4-in. pipes a distance of about 50 ft. from their present termination and placing clean gravel about them, as it was originally placed, adjacent to such pipes; then filling the trench above the gravel to a depth of 2 ft. with the washed sand which you have upon the bank, and filling above this and over the present top of the filter between the nearest carriers with the remaining sand from the excavation. This process should be continued over so much of the filter as does not allow the water to drain from the sand freely, which includes a large part of the easterly half of the filter and a small portion of the remainder.

"When the filter was constructed, you were advised that the whole surface should be cleaned once a month, and that certain portions should be cleaned oftener in times of freshets. Your records show that the easterly portion of the filter has been allowed to remain uncleaned in the cold season a much longer time, even reaching a period of four or five months, while the portion nearer the pumping station has been cleaned more frequently. To this fact is probably due the larger deposit of iron in the gravel of the easterly portion, and the Board regards it important that the original instruction in regard to cleaning the filter should be carried out to maintain its efficiency. To accomplish this, it is, in the opinion of the Board, necessary that the filter be covered, to effectually prevent the formation of ice upon its surface.

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"Upon completing the relaying of the underdrains and upon restoring the filter bed to its original depth, it should hereafter be maintained at that depth; and, to keep it in the most efficient condition for purifying the water, it should be run intermittently, as originally designed.

"You have found the filter delivering an abundant supply of water during the past four months, but from this you cannot conclude that it will continue to do so, for during the season of the formation of ice the sand will allow only about two-thirds as much water to pass through it as in summer. Your experience of last winter shows that it is necessary to act promptly.

"By entering upon the work of covering the filter with a roof to prevent freezing and of removing the gravel clogged with iron without delay, it is probable that enough work can be done before the beginning of winter to insure a sufficient supply of filtered water for the city."

On October 1st, the Lawrence Water Board submitted the foregoing communication to the City Council, with the request that a sum of money, not exceeding $37 000, be appropriated for the construction of a cover over the filter. At the same time the Council was informed that it was the intention of the Board to proceed at once with the work of reconstruction of the underdrains in accordance with the recommendations of the State Board of Health.

Renewals in 1898.—The work during this year consisted of the excavation of several beds in the easterly portion of the filter, which investigation had shown to be most clogged, the relaying of the pipe underdrains and underdrain material, and the replacing of old and new sand to the original grade of the surface; together with the screening and washing of various sizes of gravel and sand, in amounts sufficient for the work. All of this work was under the direct charge of Mr. Walter E. Spear, C. E., from whose report to the Water Board the writers have compiled many of the following data. Screening and washing the gravel and coarse sand was begun during the latter part of September, and was carried on until December 14th, whenever the weather permitted, except during the period of actual reconstruction of the filter beds.

Owing to the decreased rate of operation of the filter, due to its clogged condition, and the consequent diminished storage in the distributing reservoir, it became a difficult matter to obtain intervals of sufficient duration, with suitable weather, in which to carry on the actual work upon the filter. The first work of reconstruction was performed from October 18th to 21st, when the underdrain of Bed No. 13, and 16 ft. of that in Bed No. 18 were relaid. A severe storm prevented further operations, and it was not until about the middle of November that another suitable opportunity was secured. At this time, from November 14th to 18th, the underdrains of Beds Nos. 14, 15 and 19, and the remainder of No. 18 were relaid, and, together with Beds Nos. 12

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and 13, were brought to the required grade with sand. The next opportunity for labor on the filter came on December 6th, from which time work was pushed day and night to December 9th, and Beds Nos. 16, 17, 21 and 22 were improved and brought to grade.

The work of reconstruction was performed in accordance with the general recommendations of the State Board of Health. In each bed, with the exception of the first, a braced and sheeted trench 10 ft. in width was excavated, extending from the down-stream or northerly end of the underdrains, to a point near the southerly extremity of the beds, 15 ft. from the main distributing channel. The clean sand was thrown out of the trenches to each side upon the surface of the filter beds. The gravel underdrain material, which was found to be almost completely obstructed with a deposit of gelatinous iron rust, and a growth of *Crenothrix*, occurring especially in the upper layers, was wholly removed, together with the pipe underdrains.

TABLE No. 54.—Data of Underdrain Material used in Renewals in 1893.

Size of material.	Width of trench covered by material.	Depth of layers.
Inches.	Feet.	Inches.
2	3	4
1½	5	3
¾	7	1½
⅜	9	¾
$\frac{3}{16}$	9	¾
Coarse sand.	10	1
Total depth.....	.....	11

The bed of the filter, consisting of a mixed clayey and sandy material, was prepared for the relaying of the underdrains by placing over it a layer of unscreened gravel 1 in. or more in thickness. The old pipe underdrains were washed and relaid, and the lines extended in a southerly direction with 4-in. pipes, for a distance of about 50 ft. The grade of all pipes was 1 in 100, except in Beds Nos. 16, 17, 21 and 22, where the last 30 to 40 ft. were laid flat, in order to keep their elevation as low as possible. The original method of laying the pipes with open joints, so that the spigot of one approached but did not enter the bell of the next, was adhered to in reconstruction; each joint being surrounded with a 4 in. layer of 2-in. gravel. On the first gravel layer there were placed successive courses of material of the width and depth shown in Table No. 54.

A saving in the amount of 2-in. gravel surrounding the pipe underdrains was effected in Beds Nos. 16, 17, 21 and 22, by using this material at the joints for a distance of 6 ins. only, in either direction; the intermediate 12 ins. of each pipe being surrounded by 1½-in. gravel.

Upon the coarse sand, superposed on the $\frac{3}{16}$-in. gravel, there were

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deposited from 2 to 2½ ft. of fresh washed sand, and upon this the sand which was excavated from the trench was placed, bringing each bed to the original elevation as designed; or about 1 ft. higher than the grade prior to reconstruction. In Beds Nos. 21 and 22, the flow of ground-water, which had originally caused some trouble in the construction of this portion of the filter, was encountered, and necessitated particular care in bracing and sheeting, especially in the northerly portion of the beds, in order to prevent the sand from working into the trenches.

The total cost of this work, as estimated by Mr. Walter E. Spear, Engineer-in-Charge, was $5 709.58, itemized as in Table No. 55:

TABLE No. 55.—Cost of Reconstruction in 1898.

Cubic Yards.	Items.	Cost.	Per Yard.
	Material.		
90	Unscreened gravel (used over bottom)..	$60.50	$0.67
50	Screened " (from P. Holland)...	103.95	2.08
421	Gravel of several sizes (screened at city bank).....	1 770.37	4.21
451	Gravel, washed.....	1 066.38	2.36
60	Coarse sand, screened and washed.....	35.11	0.59
....	Vitrified pipe, lumber and supplies....	240.96	....
	Total for material.....	$3 277.27	
	Labor.		
1 600	Excavating and refilling trenches.....$1 008.19		$0.63
300	Removal of clogged gravel from under-drains.....	450.65	1.50
314	New gravel and drains.....	412.17	1.31
900	Washed sand in trenches.....	561.30	0.62
	Total for labor.....$2 432.31		
	Total for labor and material.....		$5 709.58
	Estimated Deduction for Unused Material.		
157	Screened gravel, several sizes.....	$553.90	
137	Washed gravel " "	323.93	
8	Coarse sand.....	4.68	$882.51
	Net actual cost of reconstruction in 1898.		$4 827.07
	Cost per bed.....	$536.43	

Results from Renewals in 1898.—An increase in the capacity of the filter became apparent immediately after the reconstruction of the first five beds; namely, Nos. 13, 14, 15, 18 and 19. As determined by the engineer in charge of the work at that time, basing an estimate upon the average rates of pumping for one day immediately before and one day after reconstruction, with conditions of loss of head and temperature reduced to 5.0 ft., and 50° Fahr., respectively, the gain in quantity received from the filter was about 20 per cent. By the same method of comparison, the apparent gain in the capacity of the filter, after the completion of the nine beds, using the results of October 16th, prior

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to the beginning of the work, and of December 14th, after its completion, was about 45 per cent.

According to an estimate made by the writers, reducing to a uniform basis the average data of the loss of head, temperature of water, rate of pumping, and actual quantities pumped for equal periods of 7 days, the apparent increase in the capacity of the filter was 33 per cent. The days used were October 12th to 18th, prior to the beginning of the work, and December 10th to 16th, after its completion; the surface condition of the filter being very nearly the same in each case, although probably slightly more favorable during the first period. A similar estimate, based upon the comparison of the first 7-day period, prior to reconstruction (October 12th to 18th), with a 4-day period immediately following a complete scraping of the surface of the filter, on April 5th and 6th, 1899, about 3½ months after the completion of the work, failed to show any increase in the capacity of the filter. However, it is likely that these later results are not wholly trustworthy, owing to the probable rapid filling of the filter after scraping, and the consequent imprisonment of air in the sand, thus producing a loss of head in excess of that which might be consistently expected with such surface conditions as obtained during the April period.

Renewals in 1900.—During the year 1899 no further work in improvement of the filter was attempted. In 1900, however, the work was resumed, four beds being rebuilt, completing the reconstruction of thirteen beds, representing the entire easterly portion of the filter. The work was carried on during the year under the direction of Mr. M. F. Collins, recently in immediate charge of the manipulation of the filter, and now Superintendent of Water-Works.

Beds Nos. 20, 23, 24 and 25 were reconstructed upon the following dates: No. 25 on May 25th; No. 24 on May 31st and June 1st; No. 23 on June 7th and 8th, and No. 20 on September 26th. The general methods of excavation and relaying used during the work of 1898 were followed during 1900, with the exception that the main conduit was cleaned and relaid, and, like the underdrain pipes, was placed upon cypress planks 2 x 8 ins. and 14 ft. long, fastened together endwise with cleats.

Table No. 56 shows the length of underdrain and conduit rebuilt, and the cost of the work directly upon each bed.

The condition of the underdrain material in all the beds rebuilt during this year was about the same as found in 1898, the gravel being greatly discolored, and choked with gelatinous iron rust, in the immediate neighborhood of the main conduit and pipe underdrains, but less clogged toward the up-stream ends of the beds, where the gravel was found to be in a fair condition. The drains and main conduits were so thoroughly choked in Beds Nos. 23, 24 and 25 that no appreciable amount of water would flow away into the main conduit at the bottom of the excavation, and pumping was required throughout the whole work.

TABLE No. 56.—AMOUNT AND COST OF WORK IN 1900.

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No. of bed.	Date of work.	Length of pipe underdrains removed.	Length of conduit removed and relaid.	Length of pipe underdrains relaid.	Extension of gravel underdrains beyond pipe.	Approximate cost of work.
20	September 26	36 ft.	30 ft.	95 ft.	10 ft.	$240
23	June 7-8	32 "	30 "	90 "	10 "	370
24	May 31–June 1	32 "	30 "	88 "	10 "	400
25	May 25	30 "	30 "	94 "	10 "	370
Totals		130 ft.	120 ft.	367 ft.	40 ft.	$1 380

NOTE.—There should be added to this sum $880, for unused material from the 1898 work, making a total of $2 260.

Results from Renewals in 1900.—An estimate has been made by the writers to ascertain the increase in the yield of the filter due to the reconstruction of Beds Nos. 23, 24 and 25, immediately after the rebuilding was accomplished, and one month and a half later. In the first case, the data of loss of head, temperature of water, rate of pumping, and actual yield of filter, for the 5 days from May 13th to 17th, having been reduced to a uniform basis, were compared with those for the 7 days from June 11th to 17th, the surface of the filter being practically in the same condition during each period. This study indicated an increase of about 41% in the yield of the filter. A comparison of the data for the first-named period with those of a period of 8 days from July 28th to August 6th, omitting July 31st and August 2d, gave an apparent increase in yield of 17 per cent. This result was probably affected by the imprisonment of air in the sand during the early days of the last period, twelve beds having been scraped on July 27th, and the filter rapidly refilled. It was also, doubtless, affected by the sanding of several beds during the period intervening since reconstruction.

Disturbance of Efficiency by Renewals.—The question whether such work can be done to a sand filter without detriment to the health of the people receiving water therefrom is an interesting and important one. The writers believe that, if carried on with the usual care which should accompany all such work, and in suitable, but not freezing, weather, this may be answered affirmatively. It is true, however, that placing sand in a reconstructed portion, unless the greatest precautions are taken, is likely to leave it somewhat more porous than the remainder of the bed. Referring to the bacterial results obtained from the Lawrence Filter, after the work performed in 1898, it is found that, directly after the operations in October and November, the increase in the number of bacteria, including *B. Coli Communis*, in the effluent was slight, and continued for a few days only. The

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December work, however, was not carried on under as favorable temperature conditions, and even with the great care exercised, the long-continued strain of steady work upon the men may have permitted some frozen sand to be replaced in the beds. Channels were thus probably formed allowing the water to pass down without proper filtration, because the number of bacteria in the effluent was high for about three weeks after the completion of the work, and *B. Coli Communis* was found for a longer period and in greater numbers than before. In addition to this evidence, there occurred, for a few weeks after the end of the period of high bacterial numbers, a marked increase in the number of cases of typhoid fever in the city. The reconstruction work carried on in 1900 did not cause any marked increase in the number of bacteria in the effluent from the filter, and the health of the city was not apparently affected thereby.

Benefits due to Renewals.—Attention has already been called to the gain in the capacity of the filter due to the relaying of clogged underdrain pipes and gravel, and it is natural to ask: Will this gain be permanent, or will the trouble re-occur? Since the improvement, the filter has been operated in a more careful and exact manner, scrapings have been uniform and have occurred at regular periods, refilling has been accomplished less rapidly than heretofore, and the water in the pump-well has not been drawn below Elevation 31. The filter, however, has not been covered, owing to a failure to appropriate money for this purpose, and, much to the regret of the Water Board and all who have the interest of the filter at heart, the process of scraping and the maintenance in general in the winter time continue to be carried on under adverse conditions. During the extreme cold weather of the past winter, however, it has been possible to avoid operating the pumps upon Sundays, the general loss of head, with the pumps running at full speed, has not reached the maximum, and high water in the reservoir has been constantly maintained.

Results of Operations.

In undertaking to answer the several inquiries of Mr. Soper, relating to the seeming "inconsistency between the filter and its results," the writers desire it to be understood that their personal ideas alone are advanced, but it is hoped that opinions from those in touch with the early investigations and construction of the filter may be received.

At the time when the Lawrence filter was designed, daily aeration of the filtering medium was regarded as necessary, in filtering Merrimac River water, in order to maintain the effective life of the nitrifying organisms and the consequent oxidation of the polluting matters contained in the applied water. Further experience, however, has shown that the oxygen dissolved in the river water is not exhausted by the work of purification. For this reason, shortly after the filter was

placed in operation, it was learned from the bacterial results and the effect upon the health of the people, that the provisions relating to the periodical uncovering of the sand surface and drawing down of the water within the sand, "so that the sand could fill with air from top to bottom," was not only unnecessary, but inexpedient. In other words, it was discovered that the water of the Merrimac River was of such a character, as regards organic matter and the amount of oxygen dissolved, that it could be efficiently purified by continuous filtration. Messrs. Knowles and Hyde.

Mr. G. W. Fuller's discussion has already adequately shown that the design of the filter, under ordinary conditions of operations, was such as to preclude rates greater than 5 000 000 or 6 000 000 galls. per acre per day. The experience of the writers, which they understand has been confirmed by several other investigators, leads them to believe that, with not too muddy waters, good results can be secured with slow sand filters operated at rates as great or even greater than those just indicated, during the warmer seasons of the year, and possibly during all but the coldest weather. The effect of this information upon the possibility of obtaining satisfactory effluents with a filter surface the parts of which are at the same time clogged to varying degrees, thus permitting some variation in rate, is obvious.

Where suitable means are provided for carrying the applied water over the surface, without disturbance of the sand or partially formed *schmutzdecke*, back-filling with filtered water does not appear to the writers to be necessary. In the design of the Lawrence filter, advantage has been ingeniously taken of this possibility.

The essential features of sand filters for intermittent or continuous filtration are the same, the only differences being those of detail relating for the most part to processes of draining and filling, and these are not such as to be a bar to continuous operation with a water which can thus be satisfactorily purified.

An interesting feature in the design of the Lawrence filter is the provision for the greatest lateral filtration, before reaching the underdrain system, of all water passing through those portions of the sand body having least depth.

Mr. G. W. Fuller, on page 333, has called attention to a most important question, and it is hoped that students of filtration will succeed in producing some more determinative method of indicating the value of sands as filtering mediums than the present makeshift of stating the percentage of grains of certain sizes.

Expense of Maintenance.

So far as the writers are aware, the general subject of the disturbance of work by rain and the difficulty in scraping caused by light falls of snow, introduced by Mr. Bailey (page 323) and Mr. Collins (page 328), is one to which reference has not previously been made in

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the discussion of the operation of uncovered filters. This is another reason in favor of providing covers for sand filters in climates warmer than those which have hitherto been regarded as sufficiently mild for open construction. If the writers correctly interpret the general consensus of opinion, there is a growing tendency to cover filters in many cases where formerly it was considered unnecessary.

Mr. Hazen's deduction of figures on pages 313 and 314, showing the relative economy of the Lawrence filter compared with the Albany plant, on the basis of actual cost of filtration including fixed as well as operative charges, is certainly most interesting, and, to those who have not studied relative cost from this standpoint, somewhat unexpected.

The writers cannot but feel especially gratified that so many detailed figures of the comparative cost of operating certain representative American filter plants have been advanced. All these studies point to the fact that great saving can and should be effected in the cost of conveying. In all the larger filtration projects of the future, this item will doubtless receive much consideration, and it is reasonable to expect that decided advantage will be gained by the use of mechanical appliances for this work.

Chemical and Bacterial Results.

Unfortunately, so far as the authors are aware, no measurements to determine the quantity of ground-water entering the main conduit and old filter gallery have been made. If some water were derived from the river by infiltration through the embankment and through the bottom of the filter, there would be little reason to expect any increase in chlorine, or an appreciable increase in hardness or total solids. Moreover, all evidence in canal and river work at Lawrence goes to show that, in a very short time after any disturbance, the bank and bed of the stream become so completely clogged with silt as to render them practically impervious.

The area of the superficial water-shed directly tributary to the filter is so small as to preclude the possibility of any considerable portion of the daily supply coming from that source. It is quite possible, however, that the actual area of territory tributary to the filter may be much greater than the apparent water-shed. Perhaps it is the yield of water from such a district which is responsible for the very considerable difference between certain constituents found in river water and those found in the water in the pump-well. Table No. 17 shows that the hardness of the effluent has been increased beyond that of the applied water, an average of about 40%; the total solids by an average of possibly as much as 25 to 30%, and chlorine by about 9 per cent. The excess of these constituents has been less in recent years. The average amount of iron found in the effluent of the filter during 1899 is stated in the report of the Massachusetts State

Board of Health as 0.54 part per million, but the amount present in the applied water is not given. Messrs. Knowles and Hyde.

A series of samples, analyzed under the direction of the writers, was collected on July 15th, 1901, from the following sources: Merrimac River, opposite intake of filter; effluent from underdrain of Bed No. 4; effluent of entire filter; ground-water entering filter gallery near manhole. The results of the analyses of these samples are given in Table No. 57.

TABLE No. 57.

Source.	Color.	Parts Per Million.						
		Silica turbidity.	Total solids.	Loss on ignition.	Oxygen consumed.	Chlorine.	Iron.	Total hardness.
Merrimac River.....	.....	10	84	44	9.6	4.1	1.18	13
Underdrain, Bed No. 4...	0.24	10	62	50	6.3	3.8	0.30	29
Effluent of filter.....	0.36	5	122	68	6.8	5.2	0.58	33
Ground-water.....	0.06	5	121	70	5.7	4.5	0.13	65

The samples indicate that the total solids, total hardness and chlorine are much greater in the filter effluent than in the river water. The amount of iron in solution in the ground-water as collected was less than in the effluent of the filter, and the chlorine was also lower. The total hardness of this sample was nearly double that of the effluent of the filter, but the total amount of solids contained was about the same.

It will be noted that Table No. 23, showing the free ammonia present in the Merrimac River as given by Mr. Hazen, does not accord with the figures compiled by the writers in Table No. 17. Mr. Hazen's figures represent the averages of monthly samples analyzed at the Boston laboratory of the Massachusetts State Board of Health, being the only series for the full period mentioned and used by him; while the figures used by the writers are the averages of weekly samples collected from the same place and analyzed at the laboratory of the Lawrence Experiment Station, and for the shorter period represent a greater number of samples, and thus are better to use.

In regard to the general decrease year by year in the numbers of bacteria present in the water of the Merrimac River and in the filter effluent, to which attention has been called by Mr. Soper, the writers do not feel competent to assign any definite cause. They feel confident, however, that the results for river and filtered waters for stated periods are directly comparable. Methods of laboratory procedure in bacteriological analysis of waters have undergone some change, and it is quite certain that the results given have been the best product of the times. It is known, however, that many large streams seem to have certain cycles in which less numbers of bacteria are found for a

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time; and it is also true that as a filter grows in age the effluent contains fewer bacteria, and disturbances formerly causing serious effects then seem to occasion no trouble.

Mr. Whipple's discussion is particularly interesting, and throws light on the troublesome question as to whether covered reservoirs, in which to store filtered water, are needed.

Prevalence of Typhoid Fever in Lawrence.

In Mr. Hazen's discussion of the actual benefit secured by the use of filtered water, as shown by the decreased prevalence of typhoid fever in Lawrence, the effect upon the health of the people of Lawrence caused by the introduction of a purer water supply by the City of Lowell appears not to have been directly included. The consequent very marked decrease in the number of cases of typhoid fever occurring in that place (Lowell doubtless being the chief and the most direct source of infection of Merrimac River water with the germs of the disease in question) must have been influential in reducing the sickness from typhoid fever in Lawrence, even if the river water were continued in use without purification. This fact must be regarded as offsetting in some measure the general increasing pollution of the river water during recent years. Other discussions state that the writers' estimate of usefulness of the filter is too large, and for these and other reasons the writers still believe that their original estimate of the efficiency of the filter, viewed from the standpoint of the reduction of the typhoid fever death rate, is rational. It is not unreasonable, however, also to assume that the filter has been instrumental, as Mr. Hazen suggests, in reducing the general death rate, particularly in so far as this is affected by deaths from diarrhœal diseases. But above all, in agreement with Mr. Soper's statement, the writers believe that, whatever the actual numerical estimate, the whole work and expenditure has been worth more than all it cost.

The writers heartily agree with the views expressed that "percentage of removal" is not the only criterion of efficiency of filtration, but the residual numbers of bacteria in the effluent of a filter is a more definite gauge when the influent contains large numbers. Especial significance is attached to this view, in the minds of the writers, as recent studies coming under their observation point to the fact that *B. Coli Communis*, the representative bacterium indicating sewage contamination, passes through ordinary sand filters in as great if not greater proportion than bacteria of other species with which it is present in the applied water.

The statements in the last few paragraphs of Mr. Tribus' discussion are to the point, and the writers believe that where the cost is not unnecessarily large. and under other favorable conditions, a pure supply from uncontaminated mountain sources has advantages over a purified water from a sewage-polluted stream.